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An Interim Report

EFFECT ON STREAMFLOW of FOUR FOREST PRACTICES

in the Mountains of West Virginia

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NOTICE

This U. S. FOREST SERVICE RESEARCH PAPER is the first of a new series of research publications by the Northeastern Forest Experiment Station. In this new series, which has been adopted as standard for all the Forest and Range Experiment Stations of the U. S. Forest Service, the symbol NE will designate publications of the Northeastern Station.

This new series replaces the Northeastern Station's series formerly known as Station Papers. In like manner, the series of Forest Research Notes previously published by the Northeastern Station will be designated from now on as U. S. FOREST SERVICE RESEARCH NOTES, and will be identified by the symbol NE and a number.

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Glossary of Terms Used

c.f.s.	—cubic feet per second.
c.s.m.	—cubic feet per second per square mile.
area-inch	—1 inch depth of water over the area considered.
p.p.m.	—parts per million; for example, parts of soil per million parts of water.
d.b.h.	—diameter breast high (4½ feet above the ground surface).
M b.m.	—thousand feet board measure.
basal area	—the area in square feet of the cross section at breast height of all the trees in a stand.
cull	—unmerchantable tree.
water-year	—May 1 to April 30.
growing season	—May 1 to October 31.
dormant season	—November 1 to April 30.

Introduction

FOR a long time we have known that the type of forest management practiced on a watershed may affect the amount and distribution of streamflow and the quality of the water produced. Studies have shown that this relationship between watershed treatment and water is not a simple one. A number of factors affect it, including soils, geology, topography, and climate. Though we know the general nature of forest treatment effects on water, we have not learned nearly enough to prescribe a specific treatment to give a specific result. We do not yet understand how to manipulate vegetation to increase or reduce water flow by specific amounts. Though we are better able to recommend practical measures to reduce erosion and sedimentation, we lack detailed knowledge of the fundamental relationships between land treatment and water pollution.

A necessary complication in managing most areas for water is that other uses must be considered also. Our mushrooming population forces us to examine means of integrating various land uses. Compromises that best serve the needs of society must be sought in the majority of cases. This is pointed up by the recent increasing emphasis on multiple use as a guiding principle of forest management in legislation, discussion, and practice.

Research, now under way in many areas, is delving into forest treatment effects on water in an effort to provide guides for such watershed objectives as flood control, increased streamflow, and clear usable water.

This report describes first results of forest watershed management research on the Fernow Experimental Forest in Tucker County, West Virginia.

Streamflow measurement was begun on five small watersheds in May 1951. For 6 years, records were gathered on rainfall, runoff, and water quality under undisturbed conditions. This was the calibration period when the natural behavior of the watersheds was measured as a yardstick to judge future runoff and water quality after the different treatments were applied. Timber was inventoried before and after treatment.

The watersheds were treated in May 1957 to February 1959. Effects of treatment are given for the 3-year period

from the start of treatment through April 1960; limited data are also given for the 1960 growing season.

The study is being continued to determine changes in streamflow resulting from regrowth in the watersheds after the initial cutting and to learn the effects of future cuttings. Concurrently, forest growth and other data are being collected to measure the long-range returns from these methods of managing the timber resource. The effects of these forest practices on deer habitat[1] and on the qualities of streamflow related to trout management[2] are also under study.

The Study Watersheds

The Fernow Experimental Forest is located in northern West Virginia (fig. 1) in mountainous country west of the main ridge of the Alleghenies. Drainage is via the Monongahela River to the Ohio at Pittsburgh. The five study watersheds, which range from 38 to 96 acres in area, are contiguous or nearly so. The topography, geology, soils and forest cover (fig. 2) are generally representative of this part of the Appalachians.

[1] Cooperative study with Division of Game and Fish, West Virginia Department of Natural Resources.

[2] Cooperative study with the Bureau of Sport Fish and Wildlife, U.S. Department of the Interior.

Figure 1.—Location of the Fernow Experimental Forest in the mountains of West Virginia.

Figure 2.—Typical terrain of the Fernow Experimental Forest.

Elevation and topography.—The study area ranges in elevation from about 2100 feet above sea level to about 2850 feet. Slopes are generally steep (table 1), and logging is difficult.

Geology and soils.—The Experimental Forest lies in the Allegheny Mountain section of the Appalachian Plateau, as described by Fenneman (1938). The watersheds are underlain by rock strata composed primarily of fractured hard sandstone and softer shale. There is apparently little storage of water in the bedrock.

Most of the soil in the watersheds is silt loam with considerable stone content. Infiltration and permeability of the undisturbed soils are high. Soil depth to bedrock ranges for the most part from 3 to 5 feet. Humus depth averages about 2½ inches; over most of the area the humus is classified as a medium mull.

Table 1.—Watershed areas, and percentage of area in different slope classes

Watershed No. and treatment	Area	Slope class, in percent			
		10-20	20-30	30-40	40+
	Acres	Percent of area			
1. Commercial clearcut	74	5	--	20	75
2. Diameter limit	38	45	5	50	--
5. Extensive selection	90	5	40	40	15
3. Intensive selection	85	70	15	15	--
4. Control	96	40	30	30	--
All watersheds	383	30	20	30	20

Table 2.—Period of logging and gross timber volumes, in thousands of board feet per acre

Watershed No. and treatment	Period of logging [1]	Gross timber volumes [2]		
		Original stand	Cut and culled	Residual stand
1. Commercial clearcut	May 1957-June 1958	9.9	8.5	[3] 1.4
2. Diameter limit	June 1958-Aug. 1958	7.1	4.2	2.9
5. Extensive selection	Aug. 1958-Nov. 1958	12.0	3.7	8.3
3. Intensive selection	Oct. 1958-Feb. 1959	8.3	1.7	6.6
4. Control	Not logged	10.6	0	10.6

[1] In the Commercial clearcut, skidroads were bulldozed during the operation; in the other three watersheds, skidroads were constructed in October 1957.

[2] Gross board-foot volumes to 8-inch top, including volumes in cull trees.

[3] Cull trees.

Forest cover.—The area had been heavily cut over between 1905 and 1910. Prior to the study, the forest was essentially uneven-aged, consisting of 50-year-old second growth, residuals from early cuttings, and pole-sized trees that came in after death of the chestnut about 30 years before. The major species present were: oaks (red, chestnut, and white), sugar maple, yellow-poplar, black cherry, and beech.

At the time of treatment all watersheds were completely forested, supporting stands averaging 7,000 to 12,000 board feet per acre (table 2). No fires or grazing by domestic animals had disturbed these stands for at least 35 years.

Climate and streamflow.—The climatic conditions under which this research was conducted and those to which its results are likely to apply are described by the following mean values determined from 9 years of record on the Fernow Forest:

Mean annual precipitation	58 inches
Mean daily temperature	48° F.
Mean daily maximum temperature	57° F.
Mean daily minimum temperature	38° F.
Average date of first frost in fall	Sept. 30
Average date of last frost in spring	May 7
Average length of frost-free season	145 days

Precipitation is well distributed through the year (fig. 3). Because of fairly shallow soils, steep slopes, and relatively little groundwater storage, flow is high during periods with considerable precipitation and falls off quickly during periods with little or no precipitation.

Annual runoff from the Control Watershed during the study period (1951-60) averaged about 24 inches, of which 7 inches came during the growing season and 17 inches in the dormant season. Four of the 9 years of record had one or more months with no flow; 9 of the 108 months had no

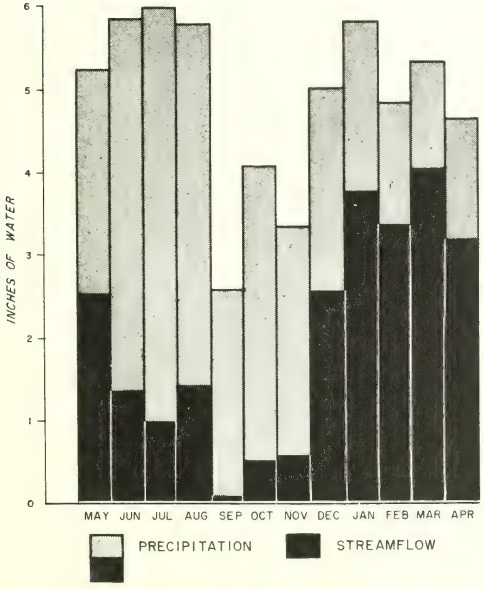

Figure 3.—Mean monthly precipitation and stream flow of the Control Watershed during the 9-year study period.

streamflow. Flow in March was the highest, with an average of 4.06 inches; September was lowest, with 0.05 inch.

On the average, 42 percent of the annual precipitation left the Control Watershed as streamflow. In the growing season, runoff was 23 percent of precipitation; in the dormant season it was 60 percent. Runoff as a percent of precipitation ranged from a high of 76 percent in March to a low of 2 percent in September. More detailed information on precipitation, temperature, and streamflow of the watersheds is given in the Appendix.

Infiltration rates are high and there is no surface runoff from these forest areas when undisturbed. Much of the precipitation from large storms reaches the stream as subsurface flow: the water passes through the soil to a less permeable layer or to bed rock; then it moves laterally downslope to the stream. It does not percolate further to groundwater.

Evapotranspiration.—Annual evapotranspiration may be estimated by subtracting annual runoff from annual pre-

Table 3.—Mean monthly precipitation and runoff of Control Watershed during 9-year study period

Month	Precipitation	Runoff	Precipitation less runoff	Runoff as percentage of precipitation
	Area-inches			Percent
May	5.26	2.53	2.73	48
Jun	5.84	1.38	4.46	24
Jul	5.99	.99	5.00	17
Aug	5.82	1.41	4.41	24
Sep	2.59	.05	2.54	2
Oct	4.03	.50	3.53	12
May-Oct	29.53	6.86	22.67	23
Nov	3.35	0.57	2.78	17
Dec	4.98	2.54	2.44	51
Jan	5.81	3.77	2.04	65
Feb	4.82	3.36	1.46	70
Mar	5.31	4.06	1.25	76
Apr	4.65	3.17	1.48	68
Nov-Apr	28.92	17.47	11.45	60
Year	58.45	24.33	[1]34.12	42

[1] As soil-moisture storage is fairly uniform at the beginning and end of the water-year this value is taken as an approximation of evapotranspiration or consumptive use. This may be an overestimate because there may be some deep seepage from the watershed.

cipitation (table 3). For the Control Watershed (No. 4) annual evapotranspiration was estimated at 34 inches in the 9-year study period. The estimates varied considerably by watershed. The following tabulation shows mean values in area-inches for the 6-year calibration period:

Watershed	*Precipitation*	*Runoff*	*Precipitation minus runoff*
1. Commercial Clearcut	60	23	37
2. Diameter Limit	59	26	33
3. Intensive Selection	59	25	34
4. Control	59	25	34
5. Extensive Selection	58	30	28

As can be seen, precipitation measured on the five watersheds was rather uniform; runoff less so. Further study of the watersheds must be made to determine whether these differences resulted from different amounts of deep seepage or from other causes.

In estimating evapotranspiration from records of precipitation and streamflow, changes in storage of water in the watershed must be considered. The water-year used in the above calculations starts and ends on May 1, when storage is generally near the maximum; and there should be little difference from year to year. For that reason, making the estimates without correction for storage should not greatly affect the result.

Potential evapotranspiration has not been calculated for these watersheds. Such investigation is planned. Indications are that actual evapotranspiration is not far below the potential.

Instrumentation and Measurement

The collection of data in this type of experimentation requires careful measurements over many years. Lack of measurement accuracy would easily mask significant differences.

Stream discharge.—On the watersheds, 120-degree V-notch weirs were used to measure stream discharge (fig. 4). Continuous records of water level were obtained on drum charts by FW-1 water-level recorders installed in concrete-block gage houses. A rating table was developed for each weir to show the relationship between gage height and discharge. From the chart record and rating table, tabulations were prepared of mean flow in c.s.m. by days. The flow was then tabulated in area-inches by month, season, and year. As needed, special tabulations of storm flow were prepared.

Precipitation.—Precipitation was measured by a network of three recording gages and nine standard gages located over

Figure 4.—A stream-gaging station on one of the experimental watersheds.

Figure 5.—Recording and standard gages installed in a clearing to measure precipitation.

the five watersheds (fig. 5). Trees were removed from the immediate vicinity of the gages to get a measure of precipitation in the open rather than under a canopy.

Air temperature and humidity.—Air temperature and relative humidity were measured at one station on the Experimental Forest area.

Water quality.—Water-quality samples were collected from the streams at sampling points a short distance above the weirs. Routine samples were taken according to schedule; special samples were obtained during storm periods. Samples were tested for turbidity and certain chemical characteristics.

In the calibration period, water temperature was measured at the time water-quality samples were taken. Starting in May 1958, maximum-minimum thermometers were placed in the streams and read and reset generally at weekly intervals.

Calibration and Analysis

During the calibration period, climatic and streamflow data were gathered as a basis upon which to predict watershed behavior after treatment. In other words, "normal" behavior pattern was established.

Changes due to treatment were determined by maintaining one of the five watersheds undisturbed as a control (Reinhart, 1958). Runoff in terms of annual, seasonal, and monthly flows and other runoff characteristics of each of the other watersheds was compared to the control during a 6-year calibration period. And mathematical equations were developed so that the runoff of each watershed could be predicted from the runoff of the control. These prediction equations were tested for validity and accuracy and were found to be statistically sound.

To illustrate simply: suppose we wish to predict annual flow of Watershed 1 (Y), or the expected discharge if there were no treatment effect, from measured annual flow of the Control Watershed (X). A linear regression equation, developed from data in the calibration period, is used. This equation is of the type: $Y = a + bX$. For this example the actual equation developed is $Y = -0.82 + 0.967X$, in which Y and X are in area-inches.

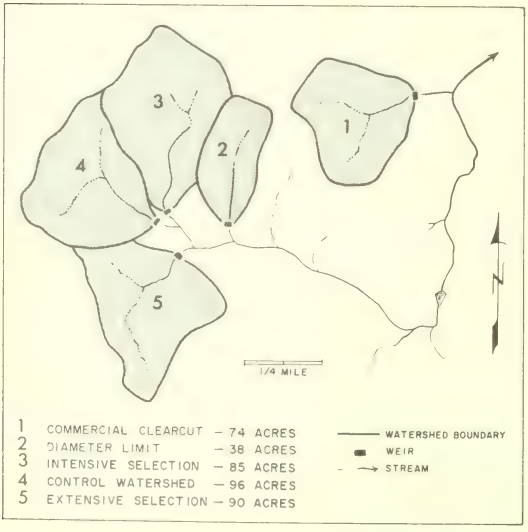

Figure 6.—Relative location and size of the five gaged watersheds on the Fernow Experimental Forest.

Now suppose we wish to test the effect of treatment on the annual flow of the Commercial Clearcut Watershed. The above equation gives a predicted or expected value. A measured value is obtained from the gaging station record. The difference between the two indicates the effect of treatment; the magnitude of this difference is then tested by routine statistical methods (Snedecor, 1956, pp. 137-138) to determine whether it is large enough to be significant.

Effects of treatment on other characteristics, say flow by season and by month, low flow, or high flow, are measured and tested in much the same way. Additional detail on calibration and analysis is given in the Appendix.

Watershed Treatment

After completion of the 6-year calibration period, timber was harvested on four of the five watersheds, each by a different forestry treatment (fig. 6). One watershed (No. 4) was left uncut to serve as a control for comparison. The four cutting practices ranged from a liquidation cutting—without concern for the future value of the property—to a conservative selection system cutting (table 4). Specifications for the four cutting practices applied were as follows:

Commercial Clearcutting.—This is the typical liquidation cutting only too commonly practiced throughout the mountain hardwood country. Everything merchantable is taken, including sawtimber and other products such as pulpwood and mine timbers in trees down to about 6 inches d.b.h. (fig. 7). All cull trees are left; no cultural work of any kind is done. Skidroads are laid out on a logger's choice basis; generally they are steep. Water values are not considered; skidroads may run up and down the stream channels, and any type of stream crossing is permissible (fig. 8). No after-logging care is practiced on the roads.

Diameter Limit cutting.—This type of cutting may be considered a crude forest management program. Every merchantable tree of long-lived species above 17.0 inches d.b.h. is cut. Every tree of short-lived species (such as black locust, sassafras, and mountain magnolia) larger than 7.0 inches is cut. The only cultural measure employed is deadening culls larger than 17.0 inches. Plans are to cut again in 20 years.

Table 4.—The four treatments applied on the Fernow watersheds

Watershed No. and treatment	Timber cut	Cutting cycle, years	Culls poisoned	Bulldozed skidroads		
				Maximum grade[1]	Water bars	Other requirements
1. Commercial clearcut	Everything merchantable	50+	None	No limit	None	None
2. Diameter limit	All merchantable trees over 17.0 inches d.b.h.	20	All over 17.0 inches d.b.h.	No limit	At 2-chain intervals	None
5. Extensive selection	Selected trees over 11.0 inches d.b.h.	10	All over 11.0 inches d.b.h.	20%	As needed	No skidding in stream channels
3. Intensive selection	Selected trees over 5.0 inches d.b.h.	5	All over 5.0 inches d.b.h. (grapevines also cut)	10%	As needed	No skidding in stream channels. Skidroads located away from stream. Grass-seeding for soil stabilization where needed.

[1] To be exceeded only for short distances where necessary.

Skidroads are logger's choice, similar to those in the Commercial Clearcutting. Only one practice is used in consideration of road values: after logging, water bars for road drainage are installed at intervals of about 2 chains (1 chain = 66 feet).

Extensive Selection management.—This is a selection management program in which harvesting and the killing of culls is limited to marked trees in the sawlog portion of the stand—trees larger than 11.0 inches d.b.h. All trees to be harvested, or deadened as culls, are marked. The only cultural measure is cull deadening and cutting of grapevines that are damaging potential crop trees. Cutting cycle is 10 years. No skidding is done in stream channels; bulldozed skidroads are limited to about a 20-percent grade except where conditions dictate a somewhat steeper grade for short stretches. Water bars are established immediately after logging wherever they appear to be needed.

Intensive Selection management.—This is a selection management program in which cutting and cultural work are done throughout the range of d.b.h.'s above 5.0 inches (fig. 9). All trees to be harvested, or killed as culls, are marked. Cutting cycle is 5 years. Bulldozed skidroads are limited to about 10-percent grade except where conditions dictate a somewhat steeper grade for short stretches. Skidroads (fig. 10) are located away from stream channels. The rule of thumb reported by Trimble and Sartz (1957) is used as a guide: distance between road and stream channel should not be less than 25 feet plus 2 feet for each percent slope of the land between road and stream. No skidding is done in stream channels; stream crossings, if necessary, are by carefully planned bridges to protect the stream. After logging, water bars are established in skidroads as necessary; and potential sediment sources, if any, are seeded to grass.

Treatment was begun on May 13, 1957; and logging on the last watershed was virtually completed on December 10, 1958. A few logs were removed from the Intensive Selection Watershed in February 1959. Data on the original stand, the amount cut, and the amount left were compiled (table 2).

In the Intensive Selection Watershed, the original volume of the stand and condition of the timber made it necessary to make a very light cutting so that sufficient volume would be available for another cut in 5 years, as scheduled under this practice. Water values were given special consideration: no logging was done in wet weather. Where necessary to insure soil stabilization, short stretches of skidroad were seeded to grass immediately after logging (fig. 11). Also, an old truck road built into the upper portion of this water-

Figure 7.—The Commercial Clearcut Watershed after logging.

Figure 8.—Tractor skidroad in the Commercial Clearcut Watershed. The road is almost in the streambed, and logging debris obstructs the channel.

Figure 9.—The Intensive Selection Watershed after logging.

Figure 10.—Tractor skidroad in the Intensive Selection Watershed just before logging. Note the gentle grade and the dip for drainage.

Figure 11.—This short stretch of skidroad in the Intensive Selection Watershed was limed, fertilized, and seeded to grass as soon as the logging operation was completed.

shed and the Extensive Selection Watershed made it possible to remove a large part of the volume from above.

In all watersheds, logging was done with a TD-9 tractor with rubber-tired sulky (fig. 12). Generally, the tractor remained on the skidroad and tree lengths were winched to it. During the course of logging no truck roads were constructed in the watersheds—only tractor skidroads.

Skidroads for the Diameter Limit Watershed and the two Selection Watersheds were constructed in October 1957, about a year before logging, to allow settling time before use and to allow a measure of the effect on streamflow of

skidroad construction alone. Water bars were installed shortly after dozing of roads. In the Commercial Clearcut Watershed, skidroads were constructed as needed during the logging job.

Most main skidroads were bulldozed; though where slopes were gentle, it was sometimes feasible to operate without 'dozing. Also, some spur roads were located on relatively steep terrain and operated without 'dozing when only a few trips were scheduled to pass over them. The disturbance caused by a few trips, even on a steep gradient, has proved to be less than would result from 'dozing a road on the grade prescribed for the treatment.

Figure 12.—Tractor with sulky skidding logs. Tree lengths were usually winched in to the skidroad.

Table 5.—Percentage of area and grade of skidroads in the four logged watersheds

Watershed No. and treatment	Percentage of watershed area		Percentage of bulldozed skidroad, by grade class--			
	In all skidroads	In bulldozed skidroads	0-10	11-20	21-30	31-40
1. Commercial clearcut	7.3	3.6	22	32	35	11
2. Diameter limit	6.2	2.5	20	72	8	0
5. Extensive selection	5.8	2.1	36	57	7	0
3. Intensive selection	1.9	.8	68	31	1	0

Detailed data were compiled separately for 'dozed and non-'dozed roads (table 5) because the amount of disturbance and impact on the watershed were much greater for the 'dozed roads. The unplanned skidroads of the Commercial Clearcut occupied the most area (7 percent of the watershed for both 'dozed and non-'dozed) and the carefully planned roads of the Intensive Selection Watershed occupied

Figure 13.—Recovery of vegetation after logging was good. Left, the Commercial Clearcut Watershed after logging was completed. Right, the same area 15 months later.

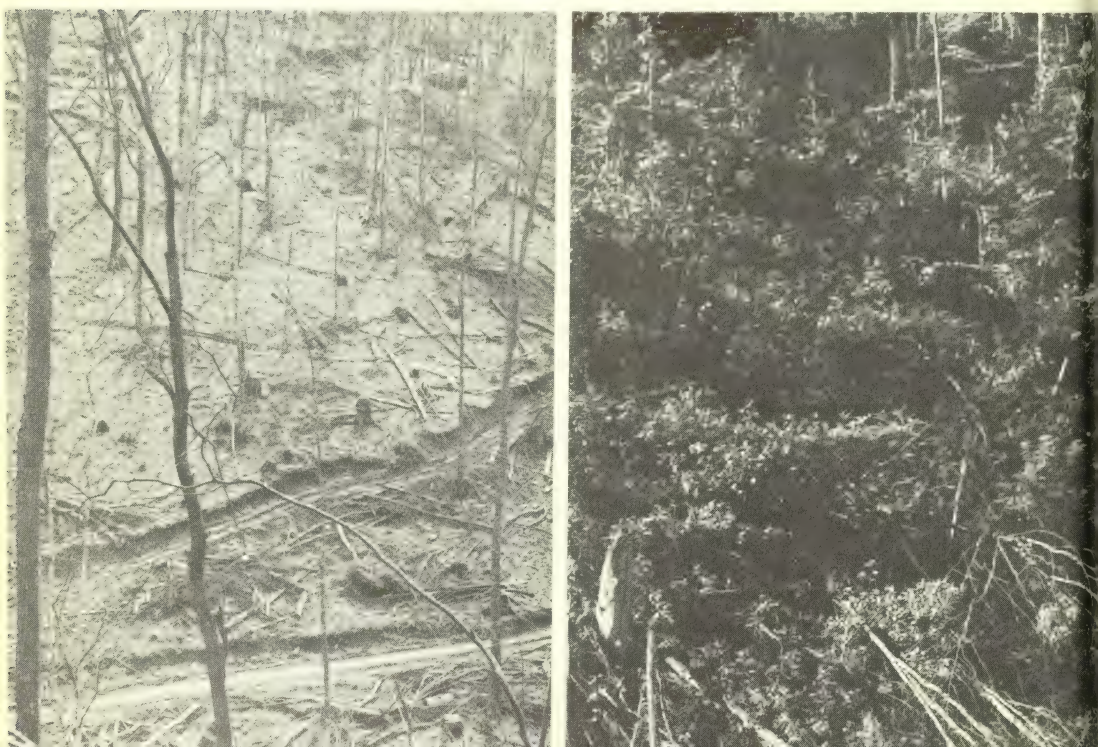

Figure 14.—Rooting depths of new and old vegetation. Left, the roots of jewel weed and nettle that came in after logging on the Commercial Clearcut Watershed. Right, roots of a large beech tree cut at edge of main skidroad in the same watershed. One-foot rule shows scale in both photos.

the least (2 percent). If the cut in the Intensive Selection Watershed had been heavier, the percent of area in skidroads would probably have been only slightly higher.

One significant feature of all treatments was the effect of logging on the forest floor. Except for the skidroad areas, the forest floor was subjected to only minor disturbance.

The recovery of the area is being watched. The forest practices used were all one-shot treatments, which will be repeated at intervals; and after each phase of the harvesting operations there is a period of recovery. Periodic inventories of trees more than 5 inches d.b.h. and periodic reproduction counts will provide a measure of the rate of recovery. Successive photographs from established photo points will provide a photo record of the changes.

Recovery was most noticeable on the Commercial Clearcut Watershed, which had the most drastic treatment (fig. 13). Shortly after logging, a good growth of new vegetation appeared, composed mostly of herbaceous plants and tree sprouts, with some admixture of tree seedlings and grass. Depth of rooting of the new herbaceous growth was much less than that of the older growth (fig. 14).

Treatment Effects

ON WATER

This study showed two things primarily: (1) that cutting of forest vegetation increases streamflow, and (2) that much of the damage to water quality due to poor skidroad practices can be avoided by proper planning of skidroads and reasonable care during logging.

The results of treatment were analyzed as to their effect on the following facets of streamflow: water quality, total discharge by year, season, and month; low flow; high flow; flow duration; and runoff as a percent of precipitation.

Water Quality

Careless logging resulted in very turbid water. This was certainly not unexpected. Maximum turbidities measured, ranging from 56,000 p.p.m. on the Clearcut to 15 on the Control (table 6 and fig. 15) illustrate the striking results of the different logging practices. Serious stream pollution was encountered on the two watersheds with unplanned skidroads—Clearcut (fig. 16) and Diameter Limit. On the Extensive Selection Watershed the effect of logging on water quality was not serious, and pollution subsided almost im-

Table 6.—Maximum turbidity measured, and frequency distribution of samples for the five watersheds, December 1957 to April 1960

Watershed No. and treatment	Maximum turbidity measured	Frequency distribution of samples, by turbidity unit* classes--				Total No. of samples
		0-10	11-99	100-999	1,000+	
	Turbidity units	Number of samples				
1. Commercial clearcut	56,000	126	40	24	13	203
2. Diameter limit	5,200	171	17	8	7	203
5. Extensive selection	210**	195	8	0	0	203
3. Intensive selection	25	201	2	0	0	203
4. Control	15	202	1	0	0	203

*Roughly parts of soil per million parts of water.

**Not included in frequency distribution. This sample was taken at a time when the other watersheds were not sampled.

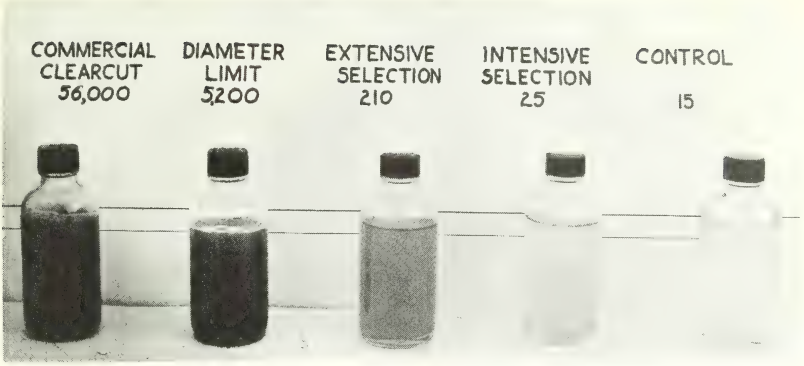

Figure 15.—Water samples showing maximum turbidities measured on each of the five gaged watersheds. Differences are due largely to differences in skidroad layout and construction.

Figure 16.—A steep, gullied skidroad in the Commercial Clearcut Watershed soon after completion of the logging operation.

Table 7.—Average turbidity of routine samples from Commercial Clearcut and Diameter Limit watersheds

(Special storm-period samples not included)

Period	Average turbidity	Range in turbidities
	Units	Units
Commercial clearcut		
During logging operation	490	0 - 5000
First year after logging	38	0 - 700
Second year after logging	1	0 - 53
Diameter limit		
Before logging (after roadbuilding)	2	0 - 68
During logging operation	897	0 - 5000
First year after logging	6	0 - 88
Second year after logging	0	0

mediately after logging ceased. The effect on water quality of logging the Intensive Selection Watershed was negligible: the water was clear, or almost clear, all of the time.

The impact on water quality was greatest during and immediately after the logging operation (table 7 and fig. 17). Repeated disturbance during logging continually brought to the road surface a new supply of fine soil particles. Erosion decreased rapidly after logging, due first to the development on our soils of a partial erosion pavement (a surface cover of small stones) and later to vegetation growth on the roads. Frost heaving brought a temporary setback to this process.

Effects of the Commercial Clearcut treatment on water temperature were noteworthy. Analysis of current temperatures in the calibration period (when extremes were not measured) indicated that there was little difference in the temperature regimes between this watershed and the Control. Thus differences during the treatment period are considered results of treatment.

Cutting in the Commercial Clearcut Watershed, as might be expected, accentuated the extremes. Growing-season maximums in 1958 and 1959 were increased on the average by 8° F. The dormant-season minimums were reduced on the average by 3½°. A slight effect in the same direction was apparent on the Diameter Limit Watershed; and no appreciable effects were evident on the two Selection Watersheds.

Figure 17.—*A*, sediment deposit at edge of main skidroad, Commercial Clearcut Watershed, one month after completion of logging operation. *B*, the same location 1 year later.

Table 8.—Effect of treatments on annual discharge

Treatment	Water-year	Discharge for year, in area-inches		Probability [1]
		Predicted	Increase	
Commercial clearcut	1957-58 [2]	19.0	2.2*	0.02
	1958-59	26.5	5.1*	.001
	1959-60	21.5	3.4*	.003
Diameter limit	1958-59 [2]	30.4	1.0	.12
	1959-60	24.9	2.5*	.01
Extensive selection	1958-59 [2]	35.3	1.0	.07
	1959-60	29.3	.7	.12
Intensive selection	1958-59 [2]	28.3	-.1	--
	1959-60	23.2	.3	.28

[1] The probability that an increase of the magnitude measured could have occurred by chance alone.

[2] Treatment in effect only part of time or on only part of the area during year.

*Statistically significant at 5-percent level.

Table 9.—Effect of treatments on discharge, by seasons

Treatment	Water-year	Growing-season discharge			Dormant-season discharge		
		Predicted	Increase	Probability [1]	Predicted	Increase	Probability [1]
		Area-inches	Area-inches		Area-inches	Area-inches	
Commercial clearcut	1957-58 [2]	2.5	1.2*	0.02	16.5	0.9	0.13
	1958-59	13.1	4.4*	<.001	13.4	.6	.23
	1959-60	2.7	3.0*	<.001	18.8	.5	.25
	1960-61	5.1	1.8*	.003	--	--	--
Diameter limit	1958-59 [2]	15.1	.7*	.04	15.5	.2	.43
	1959-60	3.4	1.8*	.001	21.4	.8	.19
	1960-61	6.2	.7*	.02	--	--	--
Extensive selection	1958-59 [2]	--	--	--	18.2	[3] -.1	--
	1959-60	4.2	1.4*	.02	24.9	-.6	--
	1960-61	7.4	[3] -.3	--	--	--	--
Intensive selection	1958-59 [2]	--	--	--	14.2	.3	.22
	1959-60	3.4	.3	.16	19.8	.0	>.5
	1960-61	6.0	.4	.08	--	--	--

[1] The probability that an increase of the magnitude measured could have occurred by chance alone.

[2] Year of treatment (treatment in effect only part of time or on only part of area).

[3] Negative value denotes a decrease.

* Statistically significant at 5-percent level.

Slight chemical changes were noted as a result of clearcutting: pH increased from a mean of about 6.1 to 6.4 and methyl orange alkalinity rose about 2 p.p.m. No appreciable changes in chemical characteristics resulted from the other three treatments.

Total Discharge

By year.—Using the equations developed from the calibration data, it was possible to predict (from the Control) the annual flow from each treated watershed if it had not been treated. When this was compared to measured flow, certain significant changes were noted (table 8).

There were large and statistically significant increases in streamflow from the Commercial Clearcut Watershed beginning the year of treatment, 1957-58. The greatest increase, 5.1 area-inches or 19 percent of the expected annual discharge, occurred the year after logging. In 1959-60, the increase was 16 percent. This drop may have been due both to increased use of water by plants as a result of vegetation regrowth and a combination of weather factors. When an after-trend has been established over a period of several years it should be possible to estimate the effect of vegetation regrowth.

The effects of treatment on the Diameter Limit Watershed, cut in mid and late summer of 1958, were not so great. In 1959-60, the first full year after logging, there was an increase of 2.5 area-inches or 10 percent.

While the record of the Selection Watersheds indicates slight increases in annual flows for the first full year after logging (1959-60) the increases were too small to be statistically significant.

Skidroads were constructed in the Diameter Limit and Selection Watersheds in October 1957. Predicted discharges and changes in flow were computed for the 1957-58 water-year; these analyses indicated that construction of skidroads, in the absence of logging, had no appreciable discharge effect on these three watersheds.

By season.—The water-year has been divided for compilation and analysis purposes into the growing season (May through October) and the dormant season (November through April). Comparisons between predicted and measured flows in these two seasons were made and tested for statistical significance (table 9).

For the first growing season after completion of logging, significant increases occurred on all but the Intensive Selection Watershed. On the Commercial Clearcut Watershed, increases were significant for all four growing seasons measured; and, as expected, the largest increase followed the completion of logging.

Increases as a percentage of expected discharge ranged up to 111 percent, which occurred on the Clearcut Watershed in 1959. The increase in 1958 was larger, 4.4 inches compared to 3.0 inches; but in the summer of 1958 precipitation and streamflow were high, which resulted in a lower percentage increase over the expected value.

Though the increase on the Intensive Selection Watershed in 1959 was not statistically significant, it amounted to 0.3 area-inch or 9 percent of the expected value and fell into a logical pattern when considered with results from the other watersheds. This 0.3 area-inch is equivalent to more than 8 thousand gallons per acre.

The effect of treatment was less in the 1960 growing season; however, increases for both the Clearcut and Diameter Limit Watersheds were still significant. In 1959 and 1960, Diameter Limit increases were about half those on the Clearcut Watershed.

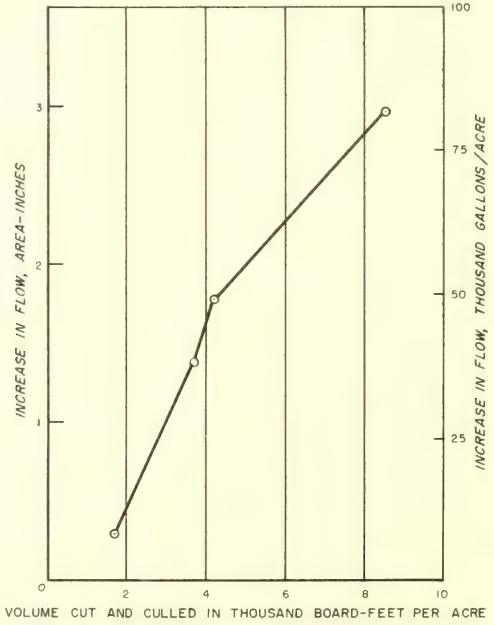

Figure 18.—Increase in flow related to volume cut and culled, 1959 growing season.

Table 10.—Increase in flow, by months, in area-inches[1]

(Increase shown only if statistically significant at 5-percent level)

Month	Commercial clearcut				Diameter limit			Extensive selection			Intensive selection	
	1957 -58	1958 -59	1959 -60	1960 -61	1958 -59	1959 -60	1960 -61	1958 -59	1959 -60	1960 -61	1959 -60	1960 -61
May	--	--	--	--	--	0.4	--	--	--	--	--	--
Jun	--	1.3	--	0.5	0.3	--	--	--	--	--	--	0.1
Jul	0.5	1.6	0.6	--	--	.4	--	--	--	--	--	--
Aug	--	1.1	.5	--	.5	.3	--	--	--	--	--	--
Sep	--	.5	.2	.7	.3	.1	0.2	0.1	0.1	--	--	--
Oct	.6	.2	1.3	.2	.1	.4	--	--	.6	--	0.1	.1
Nov	.3	.6	.9	--	.3	.5	--	--	.5	--	--	--
Dec	.5	--	--	--	--	--	--	--	--	--	--	--
Jan	--	--	--	--	--	--	--	--	--	--	--	--
Feb	.5	--	--	--	--	--	--	--	--	--	--	--
Mar	--	--	--	--	--	.4	--	--	--	--	--	--
Apr	--	--	--	--	--	--	--	--	--	--	--	--

[1] Records of runoff available for only first 6 months of water-year 1960-61.

A definite relationship appears to exist between the severity of the cut and the increase in discharge. A graph showing this relationship for the 1959 growing season, with volumes expressed in board feet, is presented in figure 18. During the dormant seasons insignificant increases were recorded in streamflow for the two most heavily cut watersheds.

Analyses were made of seasonal discharges between dozing of roads and logging on the Diameter Limit and Selection Watersheds. No significant effect of this phase of the treatment was demonstrated.

By month.—Similar analyses were made of discharges by month after start of treatment in each watershed. Table 10 presents in an abbreviated form the results of this analysis. Increases are shown only when statistically significant.

Increases in flow on the Clearcut Watershed were considerable, ranging up to 1.6 area-inches in July 1958, a month of heavy precipitation just after completion of logging. Increases in some of the drier months were small in actual amount but were large compared to expected flow; for example, in October 1957 on the Clearcut Watershed the increase was only 0.6 area-inch but measured flow was more than 10 times the expected flow.

Most of the growing-season months showed significant increases in flow on the Diameter Limit Watershed; however, increases were smaller than on the Commercial Clearcut. The two Selection Watersheds had much smaller and for the most part statistically insignificant increases in the growing-season months; however, in October 1959 both watersheds showed increases significant at the 5-percent level.

Months of the dormant season generally did not show large increases in flow. November increases were significant on the Commercial Clearcut and Diameter Limit Watersheds. Decreases that occurred in certain dormant-season months may be associated with the effect of treatment on snowmelt rates and will be discussed later.

Low Flow

An analysis was made to determine the treatment effect on the number of days in the year that stream discharge was below certain rates of flow. Three levels were considered: 0.05, 0.075, and 0.10 c.s.m., approximating 50, 75, and 100 gallons per acre per day. Table 11 gives the results for 50 gallons per acre per day; the other analyses are reported in the Appendix.

For example, it was predicted (from the relationship of the

Table 11.—Effect of treatments on number of days of low flow (less than 50 gallons per acre per day)

Treatment	Year	Number of days of low flow	
		Predicted	Decrease [1]
Commercial clearcut	1957	124	72*
	1958	38	38*
	1959	99	63*
	1960	46	39*
Diameter limit	1958	22	22*
	1959	74	47*
	1960	29	27*
Extensive selection	1959	58	21*
	1960	17	14*
Intensive selection	1959	65	5
	1960	20	13*

[1] Decrease in number of days of low flow results from an increase in streamflow.

* Statistically significant at 5-percent level.

Clearcut and Control Watersheds before treatment and the performance of the Control in 1959) that the Clearcut Watershed would discharge less than 50 gallons per acre per day on 99 different days in 1959. Actually, streamflow was below this rate on only 36 days.

The analysis shows that treatment had a strong effect on low flows: the heavier the cut, the greater the effect. In 1959 and 1960 together, days of low flow on the Clearcut were reduced from 145 to 43; on the Diameter Limit from 103 to 29; on the Extensive Selection from 75 to 40; and on the Intensive Selection from 85 to 67.

High Flow (or Storm Flow)

Analyses of high flows were difficult, largely because the effect of treatment on these flows was variable. Depending on conditions at the time of a storm, the effect might be an increase, little change, or even a decrease. High flows occurred too infrequently to group by classes based on antecedent precipitation or other factors affecting treatment results. More extensive analyses of high flows were made for the Commercial Clearcut Watershed than for the partially cut watersheds because the effects of treatment were obviously greater, as expected, on the Clearcut than on the others. Under some conditions, storm flow from the Clearcut Watershed was several times that from the Control.

Figure 19 shows sample hydrographs of these watersheds before and after treatment. Before treatment, the hydrographs of the two watersheds were close together. Number 4, the Control, was slightly above Number 1, the Clearcut. The rounded peaks on both hydrographs indicated undisturbed forested watersheds with negligible overland flow.

The hydrographs after treatment represent a 3-day period shortly after completion of logging on the Clearcut at the height of the growing, or evapotranspiration, period. The flow of the Clearcut Watershed was higher at the start; this was the normal relationship of these watersheds in the growing season after treatment. The sharp peaks on the Clearcut were probably caused by quick overland flow from skidroads. The storm flow is far greater than that from the Control. Runoff for the 3-day period, July 11 to 13, was 0.52 area-inch on the Clearcut Watershed, almost 9 times the discharge of 0.06 area-inch on the Control.

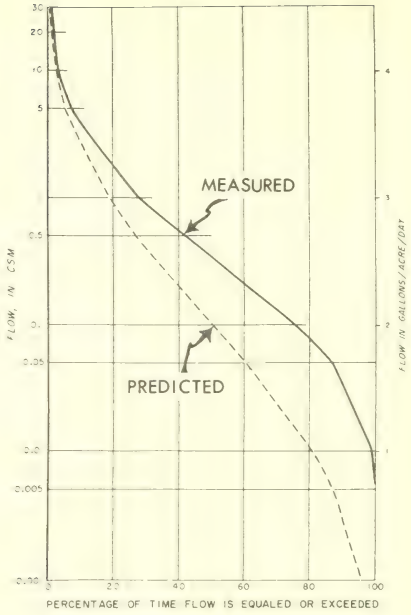

Figure 20.—Flow-duration curves for Clearcut Watershed in the four growing seasons after start of logging.

Average curves for the Clearcut Watershed in the growing seasons of the treatment period show that the treatment effect was greatest on low flows (fig. 20). Curves based on both predicted and measured values are shown; these represent flow in the 736 days of the 1957-60 growing seasons. As can be seen, the "measured" curve is far to the right of or above the "predicted" curve; this difference is a measure of the treatment effect.

The following tabulation indicates how the curves may be used and the magnitude of the treatment effect. For example, based on pre-treatment relationships, it was estimated that 25 percent of the time after treatment flow would be 560 gallons per acre per day or greater if treatment had no effect. Actually, measured flow for 25 percent of the time was 1,000 gallons per day or greater.

Percentage of time	*Flow that is equaled or exceeded, in gallons per acre per day*	
	Predicted	*Measured*
25	560	1,000
50	100	340
75	17	100

Another practical way of using these curves is indicated by an example. Assume that a certain industry or water user needs a discharge of 100 gallons per acre per day to operate at full capacity and has no facilities for impoundment. This user would have been able to operate fully only about 50 percent of the time during the growing seasons indicated if the watershed had remained in its pre-treatment condition. As a result of the clearcut treatment, it would have been able to operate fully 76 percent of the time. This advantage will diminish year by year as regrowth occurs.

The general increase in flow, the considerable augmentation of low flow, the relatively smaller increase in high flow, and the relation of these effects to severity of treatment are all readily apparent in the flow-duration curves of the four treated watersheds for two growing seasons, 1959 and 1960 (fig. 21). These were the two growing seasons immediately

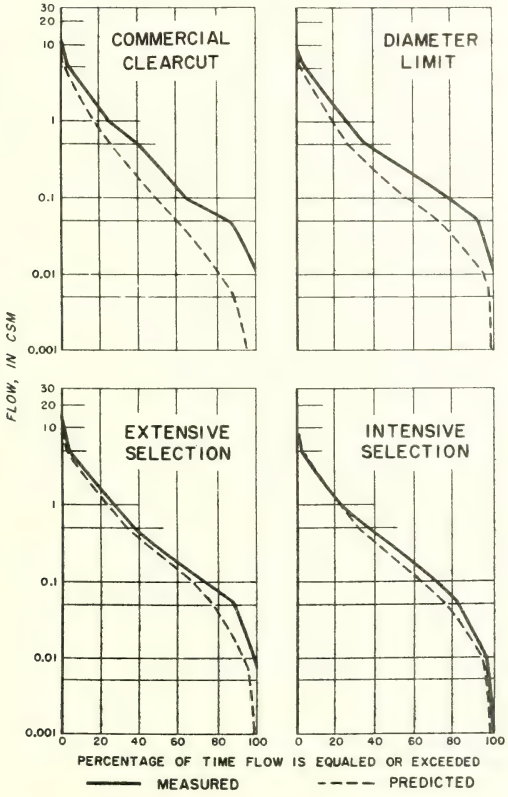

Figure 21.—Growing season flow-duration curves for the four treated watersheds in 1959 and 1960.

Table 12.—Effect of treatment on runoff as a percent of precipitation on the Clearcut Watershed

Item	Predicted runoff	Change	Change as percentage of predicted
Growing season:			
1957	11	+ 3	27
1958	34	+12*	35
1959	10	+10*	100
3-season mean	18	+ 8	44
Water-year:			
1957-58	34	+ 4*	12
1958-59	42	+ 8*	19
1959-60	36	+ 7*	19
3-year mean	37	+ 6	16

*Statistically significant at 5-percent level.

after completion of logging for all watersheds except the Commercial Clearcut; for the three watersheds, these are probably the years of maximum effect.

Runoff as a Percent of Precipitation

One interesting and often computed characteristic of a watershed is runoff as a percent of precipitation. Because the Clearcut treatment had considerable effect on stream discharge, it is not surprising that runoff as a percent of precipitation also changed. An analysis made on this characteristic showed, as expected, that the growing season changes were considerably larger than changes for the year as a whole (table 12).

As for effects of the other treatments on runoff as a percent of precipitation, for the water-year the only change measured as a result of partial cutting was an increase from 43 to 47 percent on the Diameter Limit Watershed. In the growing season, increases from 41 to 42 percent and from 12 to 18 percent were measured in 1958 and 1959, respectively. The Extensive Selection Watershed showed an increase from 15 to 20 percent in 1959. No change was noted on the Intensive Selection Watershed.

Table 13.—Stand volumes per acre on the Fernow watersheds

Treatment	Original stand volume				Residual stand volume				
	Merchantable			Cull	Merchantable			Cull
	All sawtimber	Sawtimber in log grades[1] I and II	Total		All sawtimber	Sawtimber in log grades[1] I and II	Total	
	M b.m.[2]	M b.m.[2]	Cu.ft.[3]	Cu.ft.[3]	M b.m.[2]	M b.m.[2]	Cu.ft.[3]	Cu.ft.[3]
Commercial clearcut	8.5	3.6	1,958	269	0	0	92	254
Diameter limit	6.7	2.0	1,796	83	2.8	0.6	1,063	28
Extensive selection	10.6	3.1	2,412	235	8.3	3.0	2,000	20
Intensive selection	7.6	2.9	2,021	150	6.6	2.6	1,834	0
Control	9.6	4.3	2,154	167	9.6	4.3	2,154	167

[1] U. S. Forest Service Forest Products Laboratory grades 1 and 2 based on lumber.

[2] In trees over 11.0 inches d.b.h., International 1/4-inch rule.

[3] In trees over 5.0 inches d.b.h., to a 4.0-inch top.

EFFECTS ON TIMBER PRODUCTION

The watershed treatments are replicates of four timber-management practices that are being studied on other areas in the Fernow Experimental Forest. These are all package arrangements in which a given type of management with certain methods of cutting and harvesting is studied from several viewpoints: growth, timber quality, species compostion, logging costs, and net returns.

The timber-stand data (original and residual volumes) show a partial picture of operations to date (table 13). These data alone are not sufficient for evaluating the different treatments because the study has not been under way long enough.

Fortunately records are available from treatment replicates on the other areas, some of which were placed under management more than 10 years ago. A few involve not only the first cutting in unmanaged stands but a second cutting as well. A synthesis of the watershed data and the results from other compartments, along with available information on timber growth and quality from study plots, provides a basis for comparing the four treatments.

For the first cutting, the Clearcut generally showed the greatest net return per acre because of heavy removal; and the Diameter Limit cut showed the greatest net return per M b.m. removed. This last was followed closely, and occasionally preceded, by the Extensive Selection cutting, depending on the nature of the stand. These latter two programs were concerned only with sawlogs; trees too small to produce sawlogs were ignored. The Intensive Selection program generally returned the least net income per acre and per M b.m. on the first cutting because of the concentrated effort to remove poor trees above 5.0 inches d.b.h. Also, more money was expended on cultural work and after-logging care.

In general, from all replications, the first cutting in all practices paid the logging costs and some stumpage. This was not true for the Intensive Selection Watershed. Here the very light cutting did not compensate for the road and bridge costs. These were first-cutting comparisons only and did not reflect returns from long-term management.

Discussion of Results

Results of this study add to the slowly accumulating fund of knowledge about the forest's influence on streamflow. For years forested watersheds, much like those of the Fernow, have been studied in several Eastern States and many Western States. The first study in the United States, at Wagon Wheel Gap, Colorado, dates back to 1910. In the East, the center of research has been the Coweeta Watersheds in western North Carolina, which have been studied since 1934. In all, about 60 experimental watersheds in the East, and around the same

number in the West, currently are being studied by U.S. Forest Service Experiment Stations.

To this research must be added a growing list of soil-moisture studies in which water use by forest trees is calculated by periodic soil-moisture and rainfall measurements.

We would like to relate the Fernow results to previous research. However, most of the published findings suggest that climatic, edaphic, and topographic conditions of other studies are quite different from those on the Fernow. Nor are sufficient data published to permit quantitative evaluation of these differences; accordingly, the Fernow findings cannot be correlated with those from other experimental watersheds. About all that can be said here is to point out possible reasons for broad agreements or differences.

However, the Fernow research cannot be dissociated from watershed research done or being done in other places. For that reason, some of the other watershed research is reviewed briefly in the Appendix.

Water Quality

The fact that poorly planned logging operations play havoc with water quality has been well demonstrated. This study has shown that, at least on areas comparable to the Fernow, care in logging can prevent most of the turbidity that results from logging. This fact has also been demonstrated on the Fraser Experimental Forest in Colorado. In most cases, a planned road system for timber harvest and methods of operation that protect the water resource will not cause appreciable increases in logging costs. Fernow records show that costs can often be reduced with these timber practices as compared with those of an unplanned "logger's choice" operation (Hutnik and Weitzman, 1957). In many locations, the greatest need is for an education and extension program to show operators how they can log more efficiently and at the same time conduct an operation that will conserve the water resource.

On the Fernow "logger's choice" watershed, erosion and stream turbidity rapidly diminished after logging was completed. This points up the fact that, for water-quality, after-logging care cannot be substituted for proper location of roads and good road drainage during the operation itself.

The importance of the research results on the other water-quality characteristics studied—pH, alkalinity, temperature

—is less apparent. These effects need further investigation before any recommendations for application can be made. However, it can be stated that under some conditions a clear-cutting practice may result in increases in maximum water temperatures detrimental to trout.

Water Supply

On the Fernow, forest cutting resulted in an increase in streamflow; the increase was more or less in proportion to the severity of the cutting. The amount of the increase was considerable, ranging up to 5 inches on the Clearcut Watershed the first year after completion of the logging operation. First-year increases obtained from other heavily cut-over watersheds ranged from 17 and 15 inches at Coweeta to 4.2 and 1.4 inches at Fraser and Wagon Wheel Gap, Colorado, and 3.5 inches at Kamabuti, Japan.

Usually the results of treatment are more pronounced in well-watered areas, such as the Fernow, Coweeta Hydrologic Laboratory in North Carolina, and Kamabuti, Japan. Areas of low precipitation are likely to show less effect, such as Wagon Wheel Gap in Colorado and Sierra Ancha Experimental Forest in Arizona. Treatment effects of considerable magnitude at Fraser and on the White River Watershed, Colorado, where most of the precipitation comes as snow, may likely be due to a combination of reduced interception and transpiration following killing of the conifers.

The concept of potential evapotranspiration (Thornthwaite and Mather, 1955) helps to explain these results. Potential evapotranspiration is the amount of water that is evaporated and transpired under a given set of climatic conditions when the moisture supply is unlimited. When potential evapotranspiration far exceeds the water supply available from precipitation and soil-moisture storage, a partial reduction in evapotranspiration by removal of vegetation cannot be expected to have much effect on streamflow. When the supply exceeds potential evapotranspiration and a water surplus is available for streamflow, any reduction in the amount of evapotranspiration should increase the surplus.

On the Fernow, most of the increase came in the May-to-October period; effects of treatment were not regularly shown in May and June but were generally strong in the July-to-October period. The July-to-September increases can be explained as the direct result of decreased transpiration

in those months. The October increases are associated with the effect of treatment on soil-moisture recharge: this can be considered a delayed effect of decreased transpiration in the preceding growing season. Increases in streamflow as a result of lower requirements for soil-moisture recharge often occurred in November and sometimes in December.

The timing of increases resulting from vegetation changes is not the same in all areas. In areas where the greatest effect is upon snow storage and melt, such as at Fraser, the increases will be expected to show in the spring melt period. Growing season increases are usually significant only in regions having considerable growing season precipitation, such as the Fernow, Coweeta, and Kamabuti. Often, much of the effect is shown in the soil-moisture recharge period. Depending on climate, soil depth, and other factors, there are often extreme differences in the time of year that recharge starts and in the duration of the period.

On the Fernow, with about 60 inches annual precipitation, recharge is apparently accomplished earlier than at Coshocton, Ohio, less than 150 miles away, with about 40 inches of precipitation. Streamflow changes at Coshocton were much later in the year than those on the Fernow. Maximum increases on some of the Coweeta watersheds were in the November-to-February period. This fact calls for an explanation that a detailed study of the soil-moisture regime and precipitation record might supply.

In areas with relatively low growing-season precipitation and cold winters, differences in fall soil-moisture storage due to differences in growing-season transpiration may not affect streamflow until the following spring-melt period. As evidence of this, an index of antecedent soil-moisture is often used to improve water-yield predictions based on snow surveys. Thus part of the Fraser streamflow increases, though registered in the spring, may in some years be due to reduction of transpiration the previous summer. Certainly in areas of very low growing-season rainfall, manipulating vegetation cannot be expected to provide much in the way of growing-season increases.

On the Fernow and many of the other study areas discussed, it should be stressed that the forest floor was to a large extent maintained intact. In treatments where the forest floor is severely disturbed, results are likely to be much different, e.g., heavy surface runoff during storm periods and a decrease rather than an increase in discharge in low-flow periods.

Since the Fernow studies and others indicate that heavy cutting will result in an increase in streamflow, watershed foresters may wish to put these results into practice. However, knowledge is still too meager to prescribe a specific treatment for a watershed area and to confidently predict the amount and timing of the increase.

One reason for this is the wide variety of conditions on different watersheds that affect the results of treatment. These include amount and time distribution of precipitation, temperature, soil depths, soil-moisture storage capacities, vegetation, and the like. Also, even on the same watershed, weather varies from year to year and this has a bearing on any treatment effect obtained.

Another question with respect to putting results into practice is the more or less transitory effect of forest cutting. The Fernow studies are not far enough along to determine much about the duration of streamflow increases obtained; some of the Coweeta studies show more in this respect (Kovner, 1956). The shallow rooting of the volunteer herbaceous vegetation on the Fernow Clearcut Watershed helps to explain why increased streamflow is still measured after an almost complete vegetative cover has been reestablished.

Even with the present limited knowledge, however, the watershed forester should be able to recommend a treatment to influence water yields in many areas. And he should be able to predict the direction and general magnitude of resulting changes in streamflow. For a more or less permanent increase in flow, the recommended practice would probably be one of heavy cutting on relatively small portions of the watershed in successive increments spread over a number of years. A hypothetical example of such a treatment is given in the Appendix. Other possibilities include the conversion from forest to grass or other vegetation types.

Flood Flows

On the Fernow, the effect of heavy forest cutting on high flows was variable, depending upon presence or absence of snow, antecedent soil-moisture, and probably other factors.

It is clear, however, taking the Fernow results and reviewing other research, that building up or preserving fully-stocked stands will generally be a benefit to flood control in the growing season and in the fall recharge period.

In the dormant season, after completion of the fall re-

charge period, the effect is not usually very great. Under certain conditions heavy cutting may result in decreased flows, as has been described. Somewhat the same results were noted in the investigations at Fraser and in the Harz Mountains in Germany.

In the region where the Fernow Experimental Forest is located, flood occurrence is greater in the dormant season than in the growing season. At the gaging station on the Cheat River near Parsons, West Virginia, 4 miles from the Fernow Experimental watersheds, there have been 135 occurrences of discharge above a base of about 10,000 c.f.s. (14 c.s.m) since 1913. Of these, 102 occurred in the dormant season and only 33 in the growing season.[3]

Again, it must be pointed out that none of the Fernow treatments resulted in serious disturbance of the forest floor except on limited areas of skidroads. If the forest floor had been severely disturbed much greater changes in high flows could have been expected.

Timber Values

In the management of forest lands, many uses must be considered. In research on the Fernow, water and timber are the two main uses being studied. In recommending treatments to be applied to watershed lands, the impact upon values from timber growth and harvest cannot be ignored. Generally, heavy cuttings and low stand densities, while prescribed to obtain increases in water yield, might result in a decrease in timber growth and yields. And high stand densities, while prescribed for reduction of summer flood flows, probably would result in greater growth rates. However, to utilize this growth and at the same time maintain dense stands for maximum flood protection would necessitate light and frequent harvests. Such management is generally not very profitable under present cost-and-return conditions. Economic evaluations must be made for individual areas in the light of specific physical and economic conditions prevailing there.

When we look to the future and examine the four treatments in terms of returns from continued management, we envision a financial situation different from the one defined by cost-and-return data from the first cutting. To do this,

[3] Data supplied by U.S. Geological Survey, Charleston, West Virginia.

we must draw upon our knowledge of stand development in relation to the management goals defined for each of the treatments.

We can expect the net return from the Extensive Selection Watershed to increase for several cuttings. Roads have been constructed and the most costly cultural work has been done. Considering the productivity of the sites in this watershed, the 10-year cutting should finally level off at an estimated 4 M b.m. per acre with a high proportion of the volume in desirable species and good quality logs.

Estimating future returns from the Diameter Limit Watershed is more of a problem. Growth of merchantable trees in this watershed is expected to be less than for Extensive Selection because mortality is higher with the 20-year cutting cycle and the lower level of cultural treatments leaves many small culls to occupy growing space. Also, the designation of a diameter limit for cutting allows no leeway to cut low-vigor trees below this limit or to leave high vigor ones above it. We can expect less consistent volumes in succeeding cuttings because the method used will not exercise control over spacing and size-distribution of the trees. The unit value of products from this watershed will probably be less than for the Extensive Selection Watershed because there is no opportunity, without marking of individual trees for cutting, to up-grade the stand by favoring trees of desirable species and high quality potential. As compared to Extensive Selection, forestry costs for cultural treatment and marking of trees, etc., will be lower. All things considered, it is likely that this practice will be financially feasible.

The Intensive Selection Watershed will show a future increase in volume harvested and a big increase in product value. However, costs of marking, cultural treatment, and probably logging will be higher than for the other areas. The higher cost of logging will be due to the following factors: the special care taken to protect water quality; the small volume cut per acre because of the short cutting cycle; and the higher cost per thousand of removing some trees below sawlog size. The 5-year cutting should eventually build up to about 2 M b.m. per acre which would make this a marginal operation under present market conditions when both forestry costs and logging costs are considered. Generally, returns are not likely to balance costs on many intensively-managed areas cut every 5 years unless the stands are very easily accessible and on very productive sites. There is little question that this

management practice would be profitable if the cutting cycle were lengthened.

The Clearcut Watershed will not produce another cutting equal in value to the one just made for another 60 to 80 years. It is even doubtful if a small-products operation for materials such as pulpwood can be made on a break-even basis in less than 25 years.

In discussing the relative profitability of the different treatments, the assumption was made that site productivity, or site quality, is about the same on all the watersheds. Though not strictly true, they are close enough to make this generalization. In addition, the assumption was made that all areas are easily and equally accessible. Actually, the Clearcut Watershed is less accessible than the others.

Forest Game

Deer browse and deer use have been measured for 10 years on compartments managed like the watersheds.[4] While no firm comparisons can as yet be made between management programs in respect to these factors, a tentative pattern is emerging.

After cutting, all four practices produce browse and cover. The Clearcut produces more of each for about 10 to 15 years. After this period, both browse and cover become progressively more scarce on clearcut areas. As far as deer are concerned, the developing even-aged, large-sapling, and pole stands provide neither sufficient cover nor browse.

The Intensive Selection program, with the short cutting cycle, probably provides the most constant supply of deer browse and desirable cover. In the Diameter Limit the 20-year cycle between cuttings is so long that the young vegetation that follows treatment grows beyond the deer-utilization stage before the next cutting.

No studies have as yet been made on the Fernow on the effect of the management programs on other game. However, continuing discussions of game habitat with game technicians and knowledge of forestry environment developing under these programs enable us to make a surmise on the subject.

The Clearcutting eliminates such mast as acorns, hickory nuts, and beech nuts for a long time. Squirrels are practically

[4] Cooperative study with the Division of Game and Fish, West Virginia Department of Natural Resources.

non-existent in such areas. Until trees on the clearcuts grow up to large sapling size, they provide cover for grouse. New clearcuts also provide berries as well as weed and shrub seeds, which grouse feed on. Apparently grouse, like deer, prefer new clearcuts but later on find them unattractive.

Both selection programs provide for maintaining a large part of their canopy in big vigorous trees. As a consequence, they further the production of large mast crops, which favor such mast-eating game as squirrel, turkeys, and bear, and to a lesser extent deer and grouse.

Future Research

The current studies on the Fernow Experimental Forest will be continued to: (1) measure changes in vegetation following the treatments, (2) measure the trend of treatment effects on streamflow quantity and quality, and (3) measure the effects of successive cuttings on the partially cut watersheds.

A large mass of data has been accumulated in this investigation. This report shows how that data was analyzed and interpreted. Much more knowledge about forest watershed hydrology doubtlessly can be gained from this data, and further opportunities for fruitful analysis of the data already collected will be explored.

In this experiment, and in other research, much has been learned about the effect of different forest treatments on streamflow. Much more research is needed to broaden our present knowledge and to improve management on watersheds where physical conditions vary widely and where objectives of management differ.

More basic research is needed to relate results to primary causes. To a considerable extent, results of this type of research are generally applicable and not limited to the region or locality in which the studies are conducted.

Much could be gained from a comprehensive study of the many investigations already completed in many regions of the United States and in other countries. Many data have been collected which should be subjected to intensive analysis. Correlation of various types of studies in various places should reveal the underlying reasons for differences in water quality results, differences in quantity and timing of water yield, and so on.

Fuller attainment of benefits from research already done and new research, both basic and applied, may be expected

to greatly advance forest watershed management in the next decade or two. The forest manager should then be able to prescribe sound forest watershed management practices and predict results in quantitative as well as qualitative terms.

Summary

After a 6-year calibration, four watersheds on the Fernow Experimental Forest were logged in 1957-58. Treatments ranged from a commercial clearcutting with unplanned logger's choice skidroads to a light selection cutting with planned skidroads on moderate grades. For the most part, the treatments did not seriously disturb the forest floor.

Treatments resulted in an increase in annual flow, ranging up to 5 area-inches on the Clearcut Watershed the year after treatment. Flow increases fell into a logical pattern in relation to volume cut. Most of the flow increase came into the growing season. In the 6-month period from May to October 1959, for example, increases were 3.0, 1.8, 1.4, and 0.3 area-inches for per-acre cuttings of 8.5, 4.2, 3.7, and 1.7 M b.m., respectively.

Low flows were augmented, especially for the two heavily-cut watersheds. Effect on high flows was variable. On the Clearcut Watershed some storm-period discharges in the growing season were more than doubled as a result of treatment and some snowmelt flows were reduced.

Care in the logging operation was clearly reflected in water quality. Maximum turbidities ranged from 56,000 p.p.m. on the watershed with unplanned and undrained skidroads to 25 on the watershed with carefully planned skidroads. Even on the two watersheds with unplanned skidroads, turbidities were high only during and immediately after the logging operation.

Effects of treatment are diminishing with time. Measurements on the watersheds are continuing in an effort to determine the duration of changes due to treatment and the effect of succeeding harvests on the partially cut watersheds.

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Appendix

I. CLIMATIC DATA

Precipitation and temperature records for the experimental watersheds are shown in tables 14, 15, 16, by month, season, and year in the study period. Table 17 shows streamflow of the Control Watershed.

II. INSTRUMENTATION AND MEASUREMENT

Stream discharge.—The gaging stations on the five watersheds are 120-degree V-notch weirs with FW-1 water level recorders installed in concrete-block gage houses. In construction of the concrete weir cutoff walls every effort was made to extend the wall down to bedrock or impervious subsoil so that all flow from the watershed would be over the weir blade. The weir blades are constructed of $3\frac{1}{2}$ x $3\frac{1}{2}$ inch angle iron and are bolted to the concrete wall. The upper edge of each blade is bevelled to a knife edge at a 45-degree angle. The notch is 2 feet deep.

The recorder is attached by perforated tape to a float in the stilling well below the gage house. A pen arm is actuated by the tape and records a continuous tracing on a drum-chart driven by an 8-day clock. The pen arm shows height of water surface above the low point in the V-notch.

A rating table, showing quantity of flow corresponding to any stated depth, was prepared for each weir. The rating was based upon the formula determined by Hertzler (1938) for the prototype of these weirs.

The formula is: $Q=4.43H^{2.449}$, in which Q is discharge in c.f.s. and H is head (or height of water above low point in notch) in feet. For low flows, the discharge was collected over a measured time period and weighed or measured volumetrically. Based on these measurements, the rating table determined from the above formula was adjusted for the individual weir as necessary. Adjustments were made up to heads of about 0.2 foot for three weirs; the rating table was applicable without adjustment for the other two weirs.

From the charts and the rating tables, mean daily flow in c.s.m. was computed and tabulated. Then compilations were made of flows by month, season, and year in area inches. Other tabulations were made from the charts for special purposes, such as discharge during storm periods.

Precipitation.—At the start of the study, 15 standard precipitation gages and 3 weighing-recording gages were installed on the 5 watersheds. These were distributed more or less uniformly over the area and located to sample various topographic positions. After several years of operation, analyses were made to determine whether some gages could be dropped without appreciably affecting the amount of catch. As a result, the number of standard gages was reduced to nine.

Amount of catch is determined by the standard gages. The record of the recording gages is used to break down amounts measured in the standard gages by storm, by day, or for studies involving intensities.

Precipitation on each watershed was computed by storm or by month by weighting the catches in the individual gages by the Thiessen polygon

Table 16.—Mean maximum and mean minimum air temperatures on the Fernow Experimental Forest by month, season, and year, in °F.

Month	1951-52		1952-53		1953-54		1954-55		1955-56		1956-57		1957-58		1958-59		1959-60		9-year mean	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
May	--	--	66	45	71	51	62	41	71	47	69	44	70	47	67	45	72	50	68*	46*
June	--	--	76	57	75	55	73	53	68	49	70	53	72	57	70	50	74	53	72*	53*
July	--	--	77	59	76	56	75	55	78	61	71	57	73	55	74	59	77	58	75*	58*
August	72	55	74	55	72	55	71	58	74	59	69	55	71	53	72	55	81	60	73	56
September	66	49	68	46	69	48	68	52	67	50	62	46	68	53	66	49	78	51	68	49
October	64	42	57	33	66	41	58	41	57	39	61	45	53	37	58	38	64	42	60	40
Growing-season mean	--	--	70	49	72	51	68	50	69	51	67	50	68	50	68	49	74	52	69*	50*
November	42	24	50	31	53	30	45	29	45	27	48	28	50	31	51	31	49	28	48	29
December	42	24	38	25	40	23	34	20	33	15	47	32	42	25	34	16	41	25	39	23
January	43	25	42	26	38	21	34	16	31	17	35	18	32	17	35	17	39	24	37	20
February	42	25	42	24	44	24	41	21	43	26	44	28	28	13	42	22	36	18	40	22
March	45	27	47	29	45	24	51	28	47	26	47	30	39	33	48	25	34	14	45	26
April	57	37	55	35	67	41	65	40	56	34	64	40	59	36	62	38	66	39	61	38
Dormant-season mean	45	27	46	28	48	27	45	26	42	24	48	29	42	26	45	25	44	25	45	26
Water-year mean	--	--	58	39	60	39	56	38	56	38	57	40	55	38	57	37	59	38	57*	38*

*Mean of 8 years of record.

solid matter in a sample of measured volume was filtered out, dried, and weighed to obtain suspended solids in parts per million.

For pH determination, the Hellige color comparator was used. With this instrument, indicator dyes are added to a sample of the water (Ellis et al., 1948) and the resulting color is compared to standard colors on labeled discs. This method is not the most accurate. However, it was considered adequate for the purposes of this study because the waters being

Table 17.—Streamflow of the Control Watershed by month, season, and year, in area-inches

Month	Water-year									9-year mean
	1951-52	1952-53	1953-54	1954-55	1955-56	1956-57	1957-58	1958-59	1959-60	
May	2.74	2.95	3.39	1.40	1.24	4.60	1.10	3.20	2.14	2.53
June	4.32	.24	.14	.17	.61	2.84	1.58	2.15	.35	1.38
July	.81	.04	1.19	.31	.34	1.50	.24	4.27	.21	.99
August	.03	.00	1.81	2.59	1.56	2.44	.00	4.10	.12	1.41
September	.02	.00	.00	.16	.03	.12	.00	.14	.01	.05
October	.00	.00	.00	4.00	.03	.17	.04	.03	.26	.50
May-Oct	7.91	3.24	6.54	8.64	3.82	11.65	2.95	13.90	3.09	6.86
November	.29	.01	.00	1.57	.36	.56	.07	.57	1.69	.57
December	3.75	.59	.29	3.91	1.27	4.72	3.07	1.07	4.18	2.54
January	6.53	3.93	3.03	1.62	2.53	5.31	2.18	4.38	4.40	3.77
February	1.05	3.16	1.76	5.54	7.11	5.68	2.08	2.35	1.53	3.36
March	3.09	3.69	4.48	5.58	5.41	2.28	4.46	2.94	4.61	4.06
April	3.32	3.41	1.83	1.87	2.47	3.29	5.72	3.01	3.60	3.17
Nov-Apr	18.03	14.78	11.40	20.09	19.15	21.84	17.57	14.33	20.00	17.47
Year [1]	25.95	18.02	17.93	28.74	22.97	33.49	20.53	28.22	23.09	24.33

[1] Yearly totals may differ from the sums of the semi-annual figures because of rounding.

tested are naturally free of color and because the basic comparisons were all being made from one day's operation by one observer. In this way personnel differences were largely eliminated.

For phenolphthalein alkalinity (hydroxide and normal carbonate alkalinity), phenolphthalein indicator solution was added to the water samples (Ellis et al., 1948). With the Fernow samples, no color resulted in this test and phenolphthalein alkalinity was always recorded as zero.

Methyl orange alkalinity, or total alkalinity, was determined by adding methyl orange indicator to the solution and then titrating with N/50 sulfuric acid (Ellis et al., 1948). The alkalinity in p.p.m. was determined from the amount of acid added.

The specific conductance of water is a measure of its ability to carry an electric current; hence it is an indication of the ionic strength of the solution and a measure of the amount of dissolved minerals in the water. It is determined with a meter using the principle of the Wheatstone bridge and is recorded in micromhos per square centimeter.

III. CALIBRATION AND ANALYSIS

The control-watershed concept was used in this study to compensate as far as possible for climatic variation from year to year. One watershed (No. 4 in this instance) was used as a control for each of the other four watersheds.

Prediction equations, computed from data of the 6 calibration years, are in the form of straight-line regressions; in most instances, very high correlation coefficients were obtained, indicating that the straight-line regressions are appropriate. For example, correlation coefficients for annual flow of the watersheds to be treated and the Control were 0.996, 0.996, 0.998, and 0.998 for Watersheds 1, 2, 3, and 5, respectively.

In most analyses, the regressions were based on six observations (6 years); put in another way, N equals 6. This was true even for the analyses of flow by months; there were, for example, six Julys in the 6-year calibration period. For high flows, some analyses considered the quantity of high flow in the year or season with an N of 6. Others treated individual storm flows as separate observations and the N's were larger; for example, 48 calibration-period storms were used in several of the analyses.

Analyses of water quality were handled somewhat differently. In the case of turbidity, the effects of treatment—and the differences between treatments—were of such magnitude that statistical tests of significance were considered unnecessary. For chemical tests and water temperature, comparison of paired observations by simple "t" tests was used.

After treatment, the regression equations were used, along with measured values for the Control Watershed, to compute predicted values for the treated watershed. This prediction, of course, was the value that would be expected if the treatment were without effect. Measured and predicted values were then compared, the difference being an apparent treatment effect.

The difference between individual predicted and measured values was tested by computing the error of estimate for an individual value (Y) of the treated watershed (Snedecor, 1956). The example in table 18 shows how the prediction equation was computed and how an individual after-treatment value was tested for significance.

Table 18.—Sample computation: annual discharge-prediction equation for Clearcut Watershed and test for significance of increase in discharge in water-year 1958-59

Calibration data

Water-year	Annual discharge, in area-inches	
	Control Y	Clearcut X
1951-52	25.95	24.40
1952-53	18.02	16.77
1953-54	17.93	16.55
1954-55	28.74	25.91
1955-56	22.97	21.52
1956-57	33.49	32.20

Prediction for water-year 1958-59

Measured flow of Control = 28.22 area-inches.

Measured flow of Clearcut = 31.56 area-inches.

Predicted flow of Clearcut = 0.967 (28.22) - 0.82 = 26.47

Increase in flow of Clearcut = 31.56 - 26.47 = 5.09.

Prediction equation (straight-line regression)

$\hat{Y} = 0.967X - 0.82$

$\hat{Y}$ = Estimated flow of Clearcut Watershed, assuming no treatment.

X = Measured flow of Control.

$n = 6$

$\bar{x} = 24.52$

$\bar{y} = 22.89$

$S_x^2 = 188.3947$

$r = 0.996$

$s_{y.x}^2 = 0.398$

Test of significance

$x = X - \bar{x} = 28.22 - 24.52 = 3.70$ in which X is flow of Control in test year.

$x^2 = (3.70)^2 = 13.6900$

$s_Y^2 = S_{y.x}^2 \left(1 + 1/n + x^2/S_x 2\right) = .398 \left(1 + 1/n + \left[13.6900/188.3947\right]\right)$
$= 0.4935$

$s_Y = \sqrt{0.4935} = 0.702$

$t = (Y-\hat{Y})/s_Y = 5.09/.702 = 7.25$

Determine probability by reference to graph of t over probability.

Probability = 0.001 (The probability that an increase of this magnitude occurred by chance alone. This is a test for increase, and area under one end only of the probability curve is considered.)

Reference: Snedecor, G. W. 1956. Statistical methods. 5th Ed., 534 pp. Iowa State College Press, Ames, Iowa.

In the example, the probability was computed as 0.001. In this study, the accepted level of significance was 0.05. Thus this analysis showed that there was a significant increase in annual flow in the 1958-59 water year on the Clearcut Watershed.

Analysis of covariance has not been relied upon so far in this study even though it is often recommended in experiments of this type. In most cases, too few after-treatment observations were available for covariance analysis. In analyzing for treatment effects on individual storm flows, sufficient observations were available but variances in the calibration and treatment period were not homogeneous. Homogeneity of variance in both periods is a prerequisite for covariance analysis by usual methods; therefore the stormflow data were not analyzed by covariance.

The fact that variances before and after treatment are not homogeneous is not surprising: the watersheds were as near identical as could be when selected and as a result correlations in the calibration period were naturally high; treatment purposely resulted in differences between each treated watershed and the Control and resulted in poorer correlation in this period.

When analyses were made at the close of the calibration period, it appeared that prediction equations for discharge by individual months were not precise enough to be used for determination of significance of treatment results. This was based upon an estimated 10 to 25 percent change in flow due to treatment. However, for many of the months after treatment, especially on the Commercial Clearcut Watershed, significant treatment effects were obtained. In many cases, the increase in flow resulting from treatment amounted to several hundred percent.

IV. TREATMENT EFFECTS

Water Quality

Tables 19 and 20 are given here as background information about the effects of treatment on certain chemical characteristics and on water temperature. The streams on the experimental watersheds are slightly acidic:

Table 19.—Mean pH, alkalinity, and specific conductance of water from experimental watershed, December 1957 to April 1960

Watershed	pH	Alkalinity (methyl orange) p.p.m. $CaCO_3$	Specific conductance Micromhos/cm^2
Commercial clearcut	6.4	9	38
Diameter limit	6.1	6	25
Extensive selection	6.2	6	24
Intensive selection	6.1	6	16
Control	6.1	6	17

Table 20—Maximum, minimum, and mean water temperatures on the Control Watershed by month, in °F.

Month	Water temperature[1]		
	Maximum	Minimum	Mean
May	54	47	50
Jun	58	50	54
Jul	63	54	58
Aug	62	55	58
Sep	64	52	58
Oct	58	46	52
Nov	50	42	46
Dec	45	38	42
Jan	44	38	41
Feb	44	38	41
Mar	44	35	40
Apr	53	44	48
Water-year	53	45	49

[1] Averages for two years of record; May 1958 through April 1960.

watershed mean pH values ranged from 6.1 to 6.4. Alkalinities are very low; the water is essentially unbuffered. Specific conductances are also very low, indicating that there is little mineral matter dissolved in the water. As for water temperatures, maximums measured were not very high: mean maximum for July was only 63° F. The month with the lowest mean minimum temperature was March, with 35° F. (both of these means were based on only 2 years of record).

Total Discharge

A graph was shown earlier to relate increase in flow, by seasons, to the amount of cut and cull in M b.m. per acre. Figure 22 shows a similar presentation based on basal area rather than M b.m. More complete tables showing effect of treatment on flow by individual months are presented here (tables 21 to 24).

Low Flow

Results of an analysis of number of days of low flow below 0.05 c.s.m. (approximating 50 gallons per acre per day) were presented earlier. Table 25 shows also the effect of treatment on number of days of flow below 0.075 c.s.m. and 0.10 c.s.m. (75 and 100 gallons per acre per day). This table also shows the probabilities associated with the decreases. All changes are decreases in number of days of low flow (indicating an increase in quantity of flow due to treatment) and most are significant at the 5-percent level.

Table 21.—Increase in flow on Commercial Clearcut Watershed after start of logging, by month, in area-inches

1957-58				1958-59				1959-60				1960-61			
Month	Discharge		Probability[1]	Month	Discharge		Probability	Month	Discharge		Probability	Month	Discharge		Probability
	Predicted	Increase			Predicted	Increase			Predicted	Increase			Predicted	Increase	
May	0.78	0.26	0.10	May	3.00	0.09	0.30	May	1.88	0.25	0.09	May	3.10	0.00	--
Jun	1.37	[2] -.02	--	Jun	1.85	1.27*	<.001	Jun	.32	.09	.31	Jun	1.05	.46*	0.02
Jul	.18	.48*	.01	Jul	3.99	1.60*	.003	Jul	.15	.58*	.004	Jul	.14	.22	.06
Aug	.03	.03	.43	Aug	3.83	1.14*	.003	Aug	.14	.53*	.02	Aug	.34	.29	.08
Sep	.00	.04	.15	Sep	.09	.46*	<.001	Sep	.01	.16*	.004	Sep	.35	.71*	.001
Oct	.06	.58*	<.001	Oct	.05	.16*	.001	Oct	.29	1.27*	<.001	Oct	.08	.16*	.002
Nov	.13	.27*	.01	Nov	.56	.64*	<.001	Nov	1.51	.86*	<.001	--	--	--	--
Dec	3.00	.54*	.02	Dec	1.10	-.18	--	Dec	4.05	-.30	--	--	--	--	--
Jan	1.98	.14	.22	Jan	4.26	-.11	--	Jan	4.28	-.16	--	--	--	--	--
Feb	1.83	.47*	.01	Feb	2.08	.22	.08	Feb	1.31	.20	.10	--	--	--	--
Mar	4.10	.27	.10	Mar	2.78	.08	.35	Mar	4.24	.12	.27	--	--	--	--
Apr	5.46	-.79	--	Apr	2.78	-.17	--	Apr	3.36	-.18	--	--	--	--	--

*Statistically significant at 5-percent level.

[1] The probability that an increase of the magnitude given could have occurred by chance alone.

[2] Negative value indicates an apparent decrease.

Table 22.—Increase in flow on Diameter Limit Watershed after start of logging, by month, in area-inches

1958-59				1959-60				1960-61			
Month	Discharge		Probability[1]	Month	Discharge		Probability	Month	Discharge		Probability
	Predicted	Increase			Predicted	Increase			Predicted	Increase	
--	--	--	--	May	2.41	0.42*	0.01	May	3.72	0.17	0.10
Jun	2.22	0.27*	0.04	Jun	.34	.13	.18	Jun	1.24	.17	.12
Jul	4.30	.24	.24	Jul	.18	.44*	.01	Jul	.17	.21	.07
Aug	4.21	.47*	.01	Aug	.17	.30*	.02	Aug	.38	.07	.28
Sep	.11	.28*	<.001	Sep	.03	.10*	<.001	Sep	.39	.20*	<.001
Oct	.05	.12*	.01	Oct	.32	.40*	<.001	Oct	.08	.05	.08
Nov	.58	.31*	.03	Nov	1.85	.52*	.01	--	--	--	--
Dec	1.09	[2] -.03	--	Dec	4.65	-.38	--	--	--	--	--
Jan	4.95	-.01	--	Jan	4.98	-.22	--	--	--	--	--
Feb	2.47	.05	.35	Feb	1.62	.27	.052	--	--	--	--
Mar	3.06	.00	--	Mar	4.89	.37*	.01	--	--	--	--
Apr	3.17	.02	.46	Apr	3.79	-.20	--	--	--	--	--

*Statistically significant at 5-percent level.

[1] The probability that an increase of the magnitude given could have occurred by chance alone.

[2] Negative value indicates an apparent decrease.

Table 23.—Increase in flow on Extensive Selection Watershed after start of logging, by month, in area-inches

1958-59				1959-60				1960-61			
Month	Discharge		Probability[1]	Month	Discharge		Probability	Month	Discharge		Probability
	Predicted	Increase			Predicted	Increase			Predicted	Increase	
--	--	--	--	May	2.56	0.50	0.06	May	3.89	-0.04	--
--	--	--	--	Jun	.50	.00	--	Jun	1.45	-.12	--
--	--	--	--	Jul	.37	.18	.16	Jul	.36	-.01	--
Aug	5.43	[2] -0.37	--	Aug	.23	.21	.15	Aug	.50	.14	0.23
Sep	.21	.06*	0.03	Sep	.05	.06*	.02	Sep	.70	.04	.28
Oct	.11	.02	.41	Oct	.40	.58*	.001	Oct	.15	.04	.33
Nov	.91	.16	.18	Nov	2.36	.50*	.04	--	--	--	--
Dec	1.61	-.25	--	Dec	5.35	-.57	--	--	--	--	--
Jan	5.54	-.18	--	Jan	5.56	-.27	--	--	--	--	--
Feb	2.85	.12	.31	Feb	1.87	-.03	--	--	--	--	--
Mar	3.61	-.05	--	Mar	5.58	-.27	--	--	--	--	--
Apr	3.73	.05	.34	Apr	4.44	-.21	--	--	--	--	--

*Increase is statistically significant at the 5-percent level.

[1] The probability that an increase of the magnitude given could have occurred by chance alone.

[2] Negative value indicates an apparent decrease.

Table 24.—Increase in flow on Intensive Selection Watershed after start of logging, by month, in area-inches

1958-59				1959-60				1960-61			
Month	Discharge		Probability[1]	Month	Discharge		Probability	Month	Discharge		Probability
	Predicted	Increase			Predicted	Increase			Predicted	Increase	
--	--	--	--	May	2.32	0.06	0.36	May	3.45	0.15	.20
--	--	--	--	Jun	.44	.01	.45	Jun	1.27	.14*	.049
--	--	--	--	Jul	.24	.03	.41	Jul	.23	.06	.32
--	--	--	--	Aug	.18	.03	.41	Aug	.39	[2] -.08	--
--	--	--	--	Sep	.04	.00	--	Sep	.65	-.02	--
Oct	0.06	0.03	0.051	Oct	.29	.07*	.005	Oct	.09	.06*	.01
Nov	.61	-.07	--	Nov	1.79	-.04	--	--	--	--	--
Dec	1.06	.10	.21	Dec	4.21	-.23	--	--	--	--	--
Jan	4.37	.00	--	Jan	4.39	-.11	--	--	--	--	--
Feb	2.31	.12	.25	Feb	1.53	.09	.30	--	--	--	--
Mar	2.93	-.06	--	Mar	4.40	.16	.08	--	--	--	--
Apr	3.04	.03	.14	Apr	3.59	-.02	--	--	--	--	--

*Statistically significant at 5-percent level.

[1] The probability that an increase of the magnitude given could have occurred by chance alone.

[2] Negative value indicates an apparent decrease.

Table 25.—Effect of treatment on number of days of low flow in calendar year

Watershed	Year	Days below 0.05 c.s.m.			Days below 0.075 c.s.m.			Days below 0.10 c.s.m.		
		Predicted	Decrease	Probability	Predicted	Decrease	Probability	Predicted	Decrease	Probability
Commercial clearcut	1957	124	72*	<0.001	130	66*	<0.001	140	66*	0.001
	1958	38	38*	.002	55	53*	.001	68	59*	.002
	1959	99	63*	<.001	111	63*	<.001	118	55*	.002
	1960	46	39*	.002	64	46*	.001	79	46*	.003
Diameter limit	1958	22	22*	.02	39	35*	<.001	54	40*	<.001
	1959	74	47*	.001	94	52*	<.001	105	54*	<.001
	1960	29	27*	.01	49	34*	<.001	66	37*	.001
Extensive selection	1959	58	21*	.005	70	19*	.01	76	12	.08
	1960	17	14*	.02	27	9	.09	38	3	.35
Intensive selection	1959	65	5	.19	77	7	.15	89	8	.11
	1960	20	13*	.04	34	16*	.03	52	25*	.006

*Statistically significant at 5-percent level.

High Flow (or Storm Flow)

As already stated, analysis of high-flow data was more complicated than in the case of the other characteristics studied. Of the many analyses made on data for the Clearcut Watershed (the major analysis effort), four are presented here. Features common to all four analyses:

1. Prediction equations (straight-line regressions) were developed based upon calibration-period data to relate high flow of the watershed to be clearcut (No. 1) to the Control (No. 4).

2. Precipitation in the storms causing the high flow was analyzed. When weighted precipitation of No. 1 was more than 10 percent above or below that for No. 4, the resulting high flow was not analyzed in either calibration or treatment periods.

3. High flows measured after treatment were compared with predicted flows and the amount of change determined. The probability that a change of this magnitude could have occurred by chance alone was then computed. This was done by using Student's "t" test and took into account the area in both tails of the probability curve (a two-tailed test).

Special features of each analysis:

Analysis I: Instantaneous peaks. The basic data in this analysis were the maximum instantaneous discharges in c.s.m.; flows were included when discharges on the Control Watershed exceeded 10 c.s.m.

Analysis II: Storm period discharge. The basic data in this analysis were the volumes of discharge in the period between the time runoff began (SRB) and the time when the hydrograph receded to a stage midway between that at SRB and the peak. This time interval was determined on the Control. Discharge was computed for the Clearcut Watershed for the same time period.

Analysis III: Volume of discharge above 10 c.s.m. by storms. For each period of high flow, the volume of discharge above 10 c.s.m. was determined. This is equivalent to drawing a horizontal line through the hydrograph at 10 c.s.m. and determining the discharge represented by the area above the line and below the hydrograph tracing. High flows were included when discharge on either or both the Clearcut and Control Watersheds exceeded 10 c.s.m.

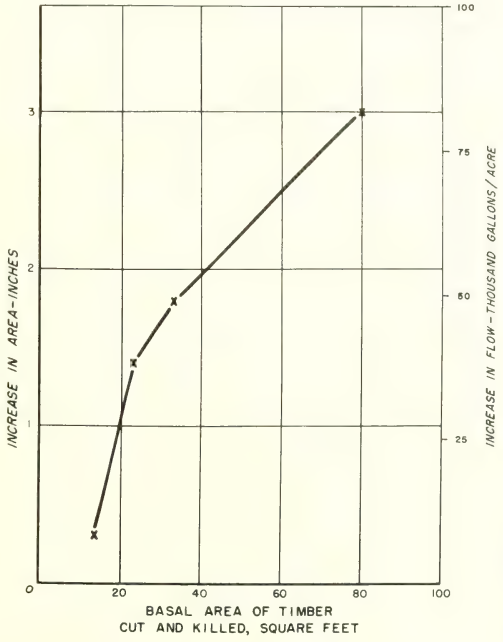

Figure 22.—Increase in flow related to basal area cut and culled, 1959 growing season.

Analysis IV: Volume of discharge above 10 c.s.m. by season and year. This analysis was based upon tabulations of mean daily flow in c.s.m. For each day of flow above 10 c.s.m., the amount in excess of 10 c.s.m. was tabulated. Totals were computed for growing season, dormant season, and year; then they were converted to area-inches. Separate prediction equations were developed for the two seasons and for the year. Days of high flow were included when mean daily discharge of either or both the Clearcut and Control Watersheds exceeded 10 c.s.m.

Comparison of the four methods.—In considering high flows, use of instantaneous peaks (Analysis I) is the most logical and easiest to explain. However, correlation studies between watersheds are not too valuable because minor differences in intensity and timing of precipitation may cause sizable differences in peaks. Also, measurement of maximum instantaneous flow is generally of little practical importance except at points of flood damage.

Storm period discharge (Analysis II) provides an arbitrary method of comparing high flows before and after treatment, with results that are suitable for statistical analysis.

One shortcoming of both these analyses resulted from the poorer correlation of high flows on the treated watershed and the Control after treatment as compared to before treatment. High flows when discharge on the Control exceeded 10 c.s.m. but that on the treated watershed was less than 10 c.s.m. were included in the analysis. When the reverse was true, data were excluded from analysis. This tended to underestimate any effect of treatment on increasing high flows.

The analysis of discharge above 10 c.s.m. (Analyses III and IV) avoided this difficulty. Of these two analyses, Analysis III (by storms) had the advantage of a larger number of observations. Analysis IV (by season or year) had fewer observations. However, particular pains were taken with these observations to reduce the variability and to increase the scientific reliability. Analysis IV was also based upon tabulations of mean daily flow which had been previously prepared and were much easier to use than determination of volumes of flow from study of the hydrograph.

Tables 26 to 29 give the results of these four analyses. They all show similar results.

The following tabulation, prepared from season and year totals in tables 26 to 29, shows the percent change in high flows resulting from the Clearcut treatment:

Period	*I Instantaneous peaks*	*II Storm-period discharge*	*III Discharge over 10 c.s.m. (by storm)*	*IV Discharge over 10 c.s.m. (by season & year)*
Growing season	+ 21	+ 24	+ 75	+ 42
Dormant season	— 4	+ 2	0	— 1
Year	+ 4	+ 7	+ 13	+ 11

In all analyses, there is a considerable increase for the growing season. The dormant season shows small changes, either increases or decreases. The annual changes are increases, but these are small when compared to those in the growing season.

Table 26.—High-flow analysis I: effect of treatment on instantaneous peaks, Clearcut Watershed

Date of storm	Peak flow			Change as percentage of predicted peak
	Predicted $\hat{Y}$ in c.s.m.	Change		
		$Y - \hat{Y}$ in c.s.m.	Probability	
	GROWING SEASON (7 storms)			
5/5/58	21.9	+ 0.5	0.91	--
6/14/58	11.9	+19.2*	<.001	--
6/22/58	17.7	+ .5	.91	--
7/21/58	39.4	+ 3.6	.41	--
8/1/58	26.3	- .3	.94	--
8/4/58	19.5	+ .3	.94	--
8/8/58	39.9	+13.2*	.004	--
Growing-season total	176.6	+37.0	--	21.0
Growing-season mean	25.2	+ 5.3	--	--
	DORMANT SEASON (13 storms)			
12/7/57	19.2	+15.7*	<0.001	--
12/26/57	17.9	0	1.00	--
1/22/58	10.0	+ 2.3	.60	--
4/28/58	66.4	- 8.1	.075	--
1/15/59	14.6	- 1.1	.80	--
1/22/59	76.5	+ 2.2	.63	--
2/15/59	10.7	+ 1.1	.80	--
11/28/59	17.1	+ 1.7	.70	--
12/12/59	41.3	- 9.4*	.035	--
1/3/60	22.3	+ 1.1	.80	--
1/15/60	18.3	- .1	.98	--
3/30/60	59.5	-21.4*	<.001	--
4/4/60	21.9	- .2	.96	--
Dormant-season total	395.7	-16.2	--	-4.1
Dormant-season mean	30.4	- 1.2	--	--
Total	572.3	+20.8	--	3.6
Mean	28.6	+ 1.0	--	--

*Significant at 5-percent level.

Explanatory Notes

Observations not included in analysis if measured precipitation on Watershed 1 was 10 percent more or less than that on No. 4 (Control).

Prediction Equation

$\hat{Y} = 1.220X - 2.34$

(X is peak flow of control in c.s.m.)

$n = 48$

$\bar{x} = 24.30$

$Sx^2 = 18,600.78$

$s_{y.x} = 4.28$

Table 27.—High-flow analysis II: effect of treatment on storm-period discharge of Clearcut Watershed

Date of peak	Storm period discharge			Change as percentage of predicted value
	Predicted $\hat{Y}$ in area-inches	Change		
		$Y - \hat{Y}$ in area-inches	Probability	
	GROWING SEASON (6 storms)[1]			
5/5/58	1.26	+0.10	0.34	--
6/14/58	.66	+ .46*	<.001	--
6/22/58	.58	+ .07	.51	--
8/1/58	.84	+ .16	.13	--
8/4/58	.60	+ .03	.78	--
8/8/58	.80	+ .30*	.006	--
Growing-season total	4.74	+1.12	--	23.6
Growing-season mean	.79	+ .19	--	--
	DORMANT SEASON (13 storms)			
12/7/57	1.15	+0.45*	<0.001	--
12/26/57	.70	+ .02	.85	--
1/22/58	.50	+ .06	.57	--
4/28/58	1.56	- .01	.93	--
1/15/59	1.04	- .10	.34	--
1/22/59	1.52	+ .18	.10	--
2/15/59	.78	+ .02	.85	--
11/28/59	.62	+ .07	.50	--
12/12/59	1.17	- .13	.22	--
1/3/60	.68	+ .03	.77	--
1/15/60	1.17	+ .03	.77	--
3/30/60	3.86	- .21	.17	--
4/4/60	1.03	- .01	.92	--
Dormant-season total	15.78	+ .40	--	2.5
Dormant-season mean	1.21	+ .03	--	--
Total	20.52	+1.52	--	7.4
Mean	1.08	+ .08	--	--

[1] One of storms in Analysis I was not used here in Analysis II because clock on Control recorder failed after the peak and part of hydrograph had to be estimated.

*Significant at 5-percent level.

Explanatory Notes

Basic data: For each storm when flow on Control exceeded 10 c.s.m., storm-period discharge is the discharge between the time when storm runoff began to the time when the stage receded to a point midway between the peak stage and the stage when runoff began. Storms with non-uniform precipitation were excluded as in Analysis I.

Prediction Equation

$$\hat{Y} = 0.981X + 0.01$$

(X is storm period discharge of the Control in area-inches)

$$n = 48$$

$$\bar{x} = 0.92$$

$$Sx^2 = 7.7170$$

$$s_{y.x} = 0.103$$

Table 28.—High-flow analysis III: effect of treatment on storm-period discharge above 10 c.s.m.

Date of peak	Discharge above 10 c.s.m.			Change as percentage of predicted value
	Predicted $\hat{Y}$ in area-inches	Change		
		$Y - \hat{Y}$ in area-inches	Probability	
	GROWING SEASON (8 storms)[1]			
5/5/58	0.219	+0.032	0.69	--
6/14/58	.028	+ .273*	.001	--
6/22/58	.138	+ .044	.59	--
8/1/58	.284	+ .033	.68	--
8/4/58	.170	+ .008	.92	--
8/8/58	.445	+ .257*	.003	--
7/25/59	.010	+ .043	.60	--
10/23/59	.010	+ .292*	.001	--
Growing-season total	1.304	+ .982	--	75.3
Growing-season mean	.163	+ .123	--	--
	DORMANT SEASON (13 storms)			
12/7/57	0.260	+0.330*	<0.001	--
12/26/57	.137	+ .019	.81	--
1/22/58	.010	+ .014	.86	--
4/28/58	.943	- .087	.30	--
1/15/59	.144	- .036	.66	--
1/22/59	.925	+ .113	.18	--
2/15/59	.014	+ .003	.97	--
11/28/59	.109	+ .045	.58	--
12/12/59	.628	- .149	.07	--
1/3/60	.210	+ .028	.73	--
1/15/60	.162	+ .006	.94	--
3/30/60	2.463	- .344*	.002	--
4/4/60	.261	- .016	.84	--
Dormant-season total	6.266	- .014	--	-0.2
Dormant-season mean	.482	- .001	--	--
Total	7.570	+ .968	--	12.8
Mean	.360	+ .046	--	--

[1] One of storms in Analysis I excluded here for same reason as in Analysis II. Two additional storms were used in this analysis (July 25, 1959 and Oct. 23, 1959). In these storms, flow of 10 c.s.m. was exceeded on the Clearcut Watershed but not on the Control. This distinction was also followed in analysis of calibration data.

Explanatory Notes

Basic data: For each storm, the amount of discharge above 10 c.s.m. was computed. This is equivalent to drawing a line across the chart at 10 c.s.m. and determining the discharge represented by the area between this line and the hydrograph tracing when the latter is above the line.

Storms with non-uniform precipitation were excluded as in Analysis I.

Prediction Equation

$\hat{Y} = 0.991X - 0.01$

(X is discharge above 10 c.s.m. on the Control)

$n = 48$

$\bar{x} = 0.311$

$Sx^2 = 6.946460$

$s_{y.x} = 0.080$

Table 29.—High-flow analysis IV: effect of treatment by season and year on discharge above 10 c.s.m. on Clearcut Watershed

Water year	Discharge above 10 c.s.m.			Change as percentage of predicted value
	Predicted $\hat{Y}$ in area-inches	Change		
		$Y - \hat{Y}$ in area-inches	Probability	
GROWING SEASON				
1957-58	0	0	--	--
1958-59	1.73	+0.51*	0.048	--
1959-60	0	+ .22	.23	--
Growing-season total	1.73	+ .73	--	42.2
Growing-season mean	.58	+ .24	--	--
DORMANT SEASON				
1957-58	1.16	+0.47*	0.01	--
1958-59	1.00	+ .06	.01	--
1959-60	3.72	- .61*	.01	--
Dormant-season total	5.88	- .08	--	-1.4
Dormant-season mean	1.96	- .03	--	--
YEAR[1]				
1957-58	1.09	+0.54*	<0.01	--
1958-59	2.64	+ .66*	<.01	--
1959-60	3.74	- .41*	.02	--
Total for year	7.47	+ .79	--	+10.6
Mean for year	2.49	+ .26	--	--

[1] Values for seasons do not sum up exactly to values for year because different prediction equations were used.

*Significant at 5-percent level.

Explanatory Notes

Basic data: Using tabulations of mean daily flow, the amount of flow above 10 c.s.m. was accumulated for each watershed (Clearcut and Control) by seasons and years. For each day of high flow, 10 c.s.m. was deducted from the mean daily value. Flows were converted to area-inches.

Prediction Equations

Growing season	Dormant season	Year
$\hat{Y} = 1.083X - 0.09$	$\hat{Y} = 0.988X + 0.01$	$\hat{Y} = 1.019X - 0.086$
$n = 6$	$n = 6$	$n = 6$
$\bar{x} = 0.62$ area-inch	$\bar{x} = 1.57$ area-inch	$\bar{x} = 2.19$ area-inch
$Sx^2 = 1.4938$	$Sx^2 = 8.0841$	$Sx^2 = 11.0537$
$s_{y.x} = 0.130$ area-inch	$s_{y.x} = 0.099$ area-inch	$s_{y.x} = 0.094$ area-inch
$r = 0.981$	$r = 0.9975$	$r = 0.998$

Due to the characteristic of the analysis, it is to be expected that percent change will be higher when the volume of discharge over 10 c.s.m. is analyzed instead of the whole storm-period flow.

Inspection of data for individual storms shows that changes in the growing season are almost universally increases—some small and some large. Changes in the dormant season may be either increases or decreases.

Discussion of dormant season variability.—General observation in the watersheds and a study of the records indicate that changes in dormant-season flow are largely the result of treatment effect on rate of snowmelt. The treatment resulted in increased insolation and more melt and streamflow on cool, sunny days. Thus less snow remained to contribute to streamflow during succeeding relatively warmer periods during which rain sometimes occurred. Snowmelt from insolation seldom results in extremely high flow. It is most effective for only a small part of the day and, because of varying aspects, on only part of the watershed area. On occasion, high flow from snowmelt occurred on the Control when a considerable portion of the Clearcut Watershed was bare of snow.

Other treatments.—So far, effect of treatment on high flows has been given for the Clearcut Watershed only. Table 30 shows a comparison with the other three treatments for area-inch increase in volume of flow over 10 c.s.m. The comparison is for the 1959-60 water-year, the only year when all four treatments were in effect.

The considerable treatment effect on the two selection-cut watersheds as compared to the other two watersheds is surprising. One reason perhaps is that the Clearcut Watershed was logged more than a year before the others and regrowth had occurred.

The 1959 growing season did not provide any large storms (flows over 10 c.s.m.) on any of the five watersheds except the Clearcut. Hence, there was no good test of storm effects. All watersheds show decreases for the 1959-60 water-year; if it had not been for the snowmelt runoff in the period March 19-29, 1960, the change for the year would have been an increase.

Table 30.—High-flow analysis: effect of treatments by season and year on discharge above 10 c.s.m. in water-year 1959-60

Item	Change in volume of discharge above 10 c.s.m., in area-inches[1]			
	Commercial clearcut	Diameter limit	Extensive selection	Intensive selection
Growing season	+0.22	0	-0.32	0
Dormant season	- .61*	- .81	- .68	-0.25*
Year	-0.41*	-1.10*	-0.99*	-0.30*

[1] Procedure of analysis same as in Analysis IV.

*Significant at 5-percent level.

The effects of treatment on high flows are not so clear as on other streamflow characteristics. More study is needed—on these watersheds and on other areas—to get a clearer picture.

Flow Duration

Figure 23 is the flow-duration curve for the Control Watershed for the 3288 days in the study period (May 1, 1951 through April 30, 1960). It gives a general picture of streamflow on the undisturbed watersheds.

To derive the flow-duration curves to show the effect of treatment on the Clearcut Watershed in the growing season, data on mean daily flows were first tabulated showing, for Watershed 4 (the Control) and for No. 1 (Clearcut), the number of days in each growing season that flow exceeded 0.001, 0.005, 0.01, 0.05, 0.1, 0.5, 1, 5, 10, 20, 30, 40, and 50 c.s.m., respectively. This was done by electronic computer.

Using data for the six growing seasons in the calibration period, prediction equations (straight-line regressions) were computed for each of the rates of flow listed above. For each growing season in the treatment period, a prediction was made for the number of days each rate of flow would be equaled or exceeded. This was made using the equation and the measured number of days for the Control in each of the treatment years. For each rate of flow, the number of days was totaled for the four seasons in the treatment period and the appropriate percentage was determined by divid-

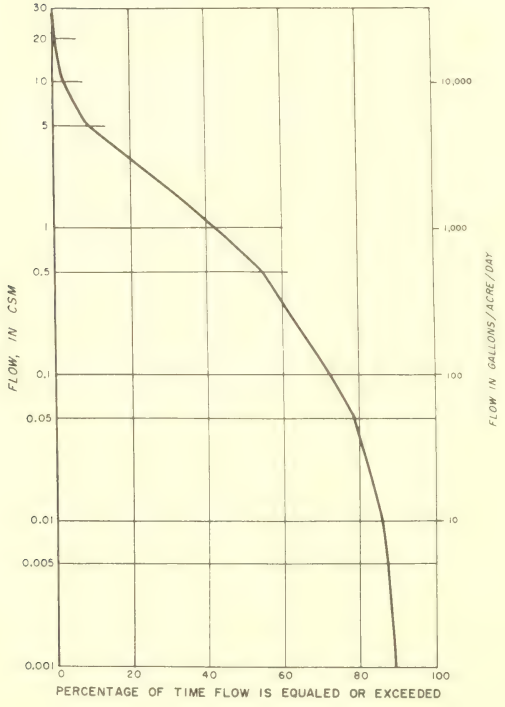

Figure 23.—Flow-duration curve of the Control Watershed in the 9 years of the study period.

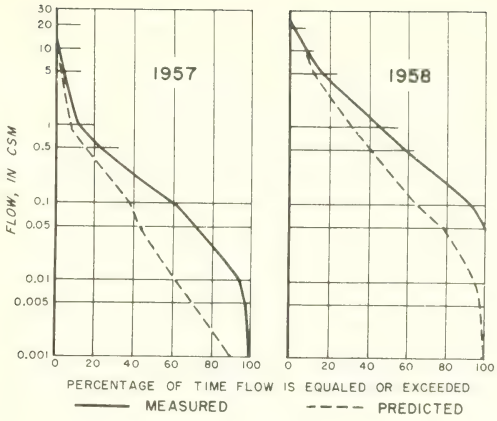

Figure 24.—Flow-duration curves for Clearcut Watershed for growing seasons in 1957 and 1958.

ing by 736, the total number of days in the four growing seasons. The resulting percentages were plotted on semi-log scale to form the *predicted* flow-duration curve.

Based on streamflow measurements on the Clearcut Watershed in the four seasons of the treatment period, the number of days and corresponding percentages were computed and plotted on the same graph to form the *measured* flow-duration curve.

The growing-season curves for the Clearcut Watershed showed the average effect on flow duration in the four seasons after start of treatment. It is of more than passing interest to examine the situation in a *dry* year and in a *wet* year, especially since water-supply problems usually occur in abnormal years rather than in years having near-average conditions.

In the 1957 growing season, there were 75 days on the Control Watershed when flow was below 5 gallons per acre per day. In 1958, there were only 3 such days. Figure 24 shows flow-duration curves of the Clearcut Watershed for these two growing seasons. The displacement to the right of both 1958 curves, when compared with those for 1957, reflects the difference in the weather of the two seasons. However, the treatment resulted in substantial augmentation of low flows in both the *wet* and the *dry* year.

Figure 25 shows the average effect of the Clearcut treatment on the flow-duration curve for 3 water-years following the start of logging. In line with other analyses, the spread between the curve based on predicted flow and the one based on measured flow is not as pronounced as that for the growing-season curves; however, the difference between the two is readily apparent.

Effects of treatment on discharge were not very large in the dormant season on any of the watersheds; therefore, flow-duration curves are not given for this season.

An additional note should be added concerning this presentation of flow-duration curves. These curves are not intended to establish whether or not the treatments had a statistically significant effect upon discharge. As analyses by water-year, season, and month that have already been presented

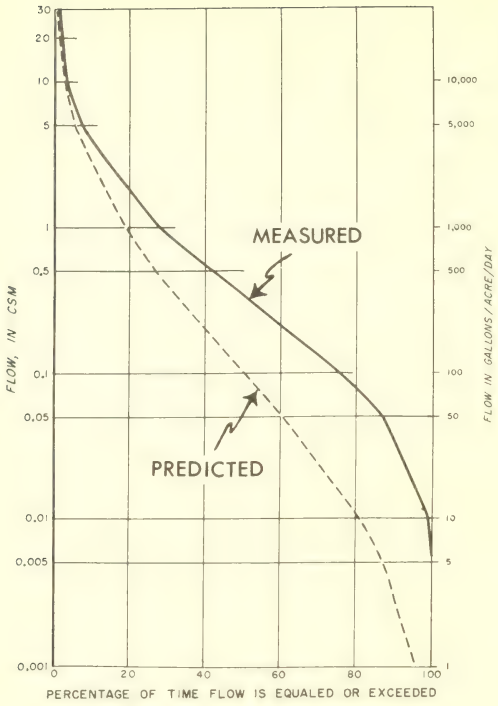

Figure 25.—Flow-duration curves for Clearcut Watershed in 3 water-years after start of logging, May 1957 through April 1960.

showed such increases in many cases, the flow-duration curves have been presented to indicate the relationship between increase and rate of discharge.

Runoff as a Percent of Precipitation

Effect of treatment on runoff as a percentage of precipitation has already been given for the Commercial Clearcut Watershed. Table 31 gives the same type of information for all four watersheds and shows the probabilities associated with the increases. As might be expected, the results are similar to those obtained in the analyses of quantity of streamflow by season and year. The results are impressive: this type of analysis appears to be a sensitive and fruitful approach to the problem of determining treatment effects.

V. DISCUSSION OF RESULTS

Following is a hypothetical example of how the research results might be used to obtain an approximation of the effect of a treatment made to increase water yield.

Assumptions:

1. Watershed under consideration is similar to Fernow watersheds in climate, soil, geology, topography, etc.
2. Effect of treatment will be the same as in Fernow experiments in 1959 and 1960.

Treatment.—Apply diameter-limit cutting practice[5] to 5 percent of watershed each year but construct skidroads to standards of the intensive-selection program. Insofar as practicable, choose each cutting area so that it includes a cross-section of aspects and slope positions.

Expected increase in discharge.—Table 32 gives the expected increase in water yield for the growing season and for two late-summer months. Any gain in flow that might occur more than 2 years after cutting is not included in the computations; this might be considered a safety factor. Increases are given in area-inches, in gallons per acre, and in terms of number of people that could be supplied.

[5] Treatment considered here is a diameter-limit cutting because of availability of research results; a different cutting practice might be more desirable for either water or timber production.

Table 31.—Effect of treatment on runoff as a percentage of precipitation on the four treated watersheds

Period	Treatment	Year	Runoff as percent of precipitation		
			Predicted	Change	Probability
Growing season	Commercial clearcut	1957	11	+ 3*	0.04
		1958	34	+12*	.001
		1959	10	+10*	.001
	Diameter limit	1958	41	+ 1	.18
		1959	12	+ 6*	.001
	Extensive selection	1959	15	+ 5*	.009
	Intensive selection	1959	13	0	.50
Water-year	Commercial clearcut	1957-58	34	+ 4*	0.007
		1958-59	42	+ 8*	.001
		1959-60	36	+ 7*	.001
	Diameter limit	1958-59	50	0	.50
		1959-60	43	+ 4*	.01
	Extensive selection	1959-60	51	0	.50
	Intensive selection	1959-60	40	0	.50

*Statistically significant at 5-percent level.

Table 32.—Computation of increased flow resulting from a diameter-limit cutting: a hypothetical example

Item	Discharge period		
	Growing season	August	September
Increase on area treated in first year after treatment ..... area-inches ..	1.8	0.3	0.1
Increase on area treated in second year after treatment ..... area-inches ..	.7	.1	.2
Mean increase on area treated ..... area-inches ..	1.25	.20	.15
gallons/acre ..	33,942	5,431	4,073
Average increase distributed over whole watershed ..... gallons/acre ..	3,394	543	407
Days in period ..... number ..	184	31	30
Average increase for watershed ... gallons/acre/day ..	18	18	14
Assumed per-capita consumption ..... gallons/day ..	50	50	50
Watershed area needed to supply one additional person from increase in flow ..... acres ..	3	3	4

Note: This example is presented as an illustration only; wide variations from watershed to watershed prevent precise quantitative estimates of practical application of these research results.

VI. OTHER WATERSHED RESEARCH

Many investigations have been made at various times and places in an effort to determine the effect of forest cutting on streamflow. The results obtained have differed greatly because of the wide variety of conditions under which the studies were made, the various treatments applied, and different study methods used.

Forest Cutting on Watersheds Calibrated with a Control Watershed

Wagon Wheel Gap, Colorado.—The historic forest and streamflow experiment at Wagon Wheel Gap, Colorado, is well known (Bates and Henry, 1928). In this experiment, started in 1910, two watersheds of about 200 acres each were calibrated for 8 years. During the experiment, annual precipitation averaged 21 inches. After calibration, one of the watersheds was denuded by cutting, piling, and burning the vegetation of Douglas-fir, pine, spruce, and aspen. Within a year after cutting, a thin stand of aspen sprouts developed. Streamflow measurements continued for 7 years after treatment.

To facilitate comparison, the records of annual flow for the Wagon Wheel Gap Watersheds have been reanalyzed in the same way the Fernow

data were analyzed. The following tabulation shows the increases in annual flow on the treated watershed at Wagon Wheel Gap:

Year	*Area-inches*	*As percent of predicted flow*	*Probability*[1]
Year of treatment	0.63*	8	0.018
First year after	1.35*	19	<.001
Second year after	1.86*	27	<.001
Third year after	0.98*	16	.002
Fourth year after	.85*	12	.004
Fifth year after	.53*	12	.029
Sixth year after	.52*	12	.031

[1]The probability that an increase of the magnitude given could have occurred by chance alone.

*Statistically significant at the 5-percent level.

The pattern of seasonal increase is of interest: 80 percent of the increase in annual flow occurred during the spring melt period (March 1 to July 10). At Wagon Wheel Gap snowmelt provided most of the annual flow. Peak flow in the spring was increased about 50 percent as a result of treatment.

Fraser Experimental Forest, Colorado.—After a lengthy calibration period, about half the merchantable timber on 714-acre Fool Creek Watershed was harvested by strip clear-cutting in the period from summer 1954 to fall 1956 (Goodell, 1958). At Fraser, annual precipitation is about 30 inches; about three-fourths of this falls as snow in the October to June period. This treatment resulted in a definite increase in annual streamflow; in 1956 the increase was 4.2 area-inches or 37 percent of the expected flow; in 1957, 3.4 area-inches or 17 percent. In 1958, the increase was 2.1 inches (Rocky Mountain Forest and Range Experiment Station, 1959). The bulk of the increases occurred during spring freshets from snowmelt. However, streamflow was also slightly higher during summer and fall in 1956 and 1957.

The spring flood peak was increased the first year after cutting and decreased in comparison with the control in the second year. In 1958, the third year after cutting, peak flow was 30 percent higher than predicted. The interaction between spring weather and treatment seems to explain the difference in spring peaks.

Sediment yields since cutting have been low due to the considerable care taken in the logging operation. For example, no timber was cut within 90 feet of the main stream.

Roads were constructed in the watershed well ahead of logging (in 1950 and 1951). No effect on water yield could be detected as a result of the 35 acres of roadway clearing.

Coweeta Hydrologic Laboratory, North Carolina.—Because of similarities in climate, forest types, topography, and methods of study, research results from the Fernow Forest can perhaps be compared with those from Coweeta better than from anywhere else. Average annual precipitation at Coweeta is 80 inches, almost all of which occurs as rain (Dils, 1957).

On Coweeta Watershed 17, all vegetation was cut and left on the ground; this was followed by an annual slashing of regrowth. Since no logging was done, there was little disturbance of the forest floor. First-year increase in streamflow was 17 area-inches. In the second year, after regrowth was cut for the first time, many herbaceous plants began to invade the area. Under this cover, the increase in water yield leveled off at about 11 area-inches from the third to the thirteenth year. Dils states, "The maximum increases came in the November to February period, but significant increases also occurred in July, August, and September—the period when municipal and industrial water shortages are most likely. Maximum peak discharges during storm periods and the distribution of streamflow were not appreciably altered . . . There has been no measurable change in stream turbidity. Air temperatures near the forest floor have increased markedly."

Coweeta Watershed 13 was treated in the same manner as No. 17 except that forest growth was allowed to come back naturally. Streamflow increase in the first year was about 15 area-inches; the increase diminished with time but was still more than 4 inches 15 years after cutting. Here, also, the greater increase occurred in the winter period. As in the case of Watershed 17, there were no measurable changes in storm peaks, volume of stormflow, or distribution of storm runoff.

After a 6-year calibration period, 212-acre Coweeta Watershed 10 was logged: 50 percent of the basal area was removed over a 3-year period. Skidroads were "logger's choice" as on the Fernow Clearcut and Diameter Limit Watersheds; truck roads were also constructed in the watershed. Logging in this manner caused extensive erosion and consequently very high stream turbidities, even in small storms; maximum turbidity measured was 5,700 p.p.m. Even after logging stopped, the exposed clay subsoil continued to move into streams after every storm, thus impairing the water quality.

This study has been reported as a demonstration of effects of exploitive logging on water quality. Apparently the effects of treatment on quantity of discharge received little emphasis; a streamflow increase of 4.0 area-inches was measured the first year after logging (Southeastern Forest Experiment Station, 1961).

Other Coweeta experiments have been conducted and reported upon but do not compare so directly with the Fernow investigations as those listed above. Some additional watershed treatments at Coweeta, not yet fully reported in the literature, have resulted in streamflow increases that were small in relation to those described above. Watershed research must seek the causes for these differences in results that apparently are not explained by the amount cut nor proportion of the stand removed.

Sierra Ancha Experimental Forest, Arizona.—Three watersheds in the Workman Creek drainage in central Arizona have been studied since 1938. The forest stand is of the mixed conifer type (Rich, 1959). Average annual precipitation is 32 inches. A logging operation and timber-stand-improvement measures in 1953, 1954, and 1955 reduced the basal area by 36 percent. No significant change in water yields had, as of 1959, resulted from this treatment.

Kamabuti, Japan.—Many investigations of the effect of forest cover and forest cutting upon streamflow have been made in foreign countries. Unfortunately, many of these have not had adequate control, so definite

conclusions cannot be drawn. One Japanese experiment is of particular interest (Maruyama and Inose, 1952). The control-watershed approach was used with a calibration period of 8 years. This experiment also gives an idea of treatment effects in an area of high average precipitation (99 inches annually) and high average streamflow (76 area-inches annually). After calibration, the mixed conifer-broadleaf stand was clearcut and the regrowth cut annually on the 6-acre treated watershed. Over a 3-year period, annual streamflow was increased by about 5 percent. Increases were significant in the summer season (June to November) but not in the winter season (December to May). Average peak runoff and increased runoff due to heavy rains for 6 examples rose more than 20 percent by cutting.

Other Investigations on Watersheds Relating Vegetation Differences to Streamflow

Sperbel and Rappen, Switzerland.—An early Swiss study, reported upon by Engler (1919) and Burger (1943) showed that streamflow from the fully forested Sperbel watershed was continuously less than streamflow from the lightly forested Rappen watershed.

Flow of Springs, California.—Biswell and Schultz (1958) report a prompt and measurable increase in flow of several springs in California following removal of vegetation by burning or cutting.

White River, Colorado.—The killing of spruce and pine by an insect epidemic affected streamflow of the White River in Colorado as reported by Love (1955). Average annual precipitation at Meeker, Colorado, is about 16 inches. In the period 1941 to 1946, the beetle killed most of the trees on 226 square miles, or 30 percent of the 762-square-mile watershed. Analysis, using nearby Elk River as a control, showed that annual flow of the White River was increased by 2.3 inches (or 22 percent) in the 1947 to 1951 period. Love estimates that an increased flow of 7.7 area-inches came from the 226-square-mile area of beetle-killed timber.

Harz Mountains, Germany.—A recent paper (Delfs et al., 1958), compared two watersheds, one forested and one clearcut, in the Harz Mountains of Germany. Annual water yield was slightly higher from the clearcut watershed; winter yield was slightly higher from the forested watershed. Flood peaks when rain followed a thaw were frequently higher from the forested area; during summer, peaks were generally higher from the clearcut area. Suspended sediment was higher from the clearcut area than the forested area.

Reforestation Experiments

This paper has dealt largely with effects of cutting, complete or partial, of the forest stand. Generally speaking, reforestation, afforestation, or the improvement of existing forest stands by protection from fire or other forest-management measures should have a corresponding effect in the opposite direction. Many studies have been conducted to determine such effects.

Coshocton, Ohio.—Reforestation of a badly eroded watershed at Coshocton, Ohio, in 1939 has resulted in a progressive decrease in annual streamflow of about 0.28 area-inch per year, amounting to about 5 inches by the 18th year of the plantation (Harrold et al., 1962). Average annual precipitation at Coshocton is about 38 inches. Decrease was divided between the growing and dormant seasons; about 70 percent of it occurred in the dormant season. This indicates that groundwater recharge has been affected to a considerable degree.

White Hollow Watershed, Tennessee.—On White Hollow Watershed in Tennessee, 588 acres out of a total 1,715 acres were reforested and other conservation methods were applied (Rothacher, 1953). No effect on annual discharge was noted. Summer peak flows were reduced 73 to 92 percent. Overland flow and soil erosion were practically eliminated.

Pine Tree Branch, Tennessee.—The Tennessee Valley Authority also investigated the effect of reforestation and other erosion-control measures upon the hydrology of 88-acre Pine Tree Branch Watershed (Tennessee Valley Authority, 1955). Watershed treatment was done largely in the period 1945 to 1948. Considering records to 1950, the report states, "There is some indication of a slow, progressive decrease in water yield, but whether or not this is significant remains to be determined by further measurements." Marked reductions in peak discharges and sediment production were measured; however, much of this is probably due to measures other than reforestation, such as contouring and check dams in stream channels and gullies.

Plot Studies

Many studies have been made of the effect of forest cutting upon soil moisture. It is logical to infer that under most conditions any treatment that results in maintaining a higher level of soil moisture will increase streamflow to some degree. Much of the information needed to corroborate and explain results determined on gaged watersheds will come from plot studies. Of the many experiments conducted, only a selected few will be mentioned here.

Crossett Experimental Forest, Arkansas.—Moyle and Zahner (1954) measured soil moisture on a number of plots at Crossett, Arkansas, during the summer of 1953. At Crossett, annual rainfall is about 50 inches and the normal for the May-September period is 18 inches. They found sizable soil-moisture differences related to stand conditions. For example, in August there was as much as 10 inches less water in the upper 4 feet of soil under an all-aged cull-hardwood stand than under a similar stand in which all hardwoods over 4 inches d.b.h. had recently been poisoned. Their summary states in part: "Where pine or hardwood stands with a stocking of 70 to 100 square feet of basal area were undisturbed, water was removed from the ground rapidly with the onset of hot dry weather. On plots where large cull hardwoods were deadened, and where all living vegetation was removed, soil water remained relatively high throughout the summer."

Fraser Experimental Forest, Colorado.—Wilm and Dunford (1948) reported on an intensive plot study conducted near Fraser, Colorado, to

determine water available for streamflow from areas cut to varying residual volumes of timber. Approximating the amount of timber cut, the following tabulation shows the annual increase in water available for streamflow:

Volume of merchantable timber cut		*Average increase available over 4-year period*	
M b.m. /acre	*Percent of total volume*	*Area-inches*	*Percent of expected value*
6	50	1.0	10
8	67	2.0	19
10	83	2.1	20
12	100	3.2	31

These increases are attributed largely to the effects of treatment on snow interception and evaporation. Autumn soil-moisture deficits (a measure of evapotranspiration during the summer) showed "only a weak average effect" of treatment. The authors point out that this effect was much stronger in the one treatment year when above-average precipitation (5.9 inches) occurred in the July to September period. In that year the deficits were as much as 1.24 inches less on the treated plots.

College Station, Texas.—Koshi (1959) studied soil-moisture trends under varying densities of oak overstory near College Station, Texas. Normal annual precipitation for College Station is about 39 inches. Throughout the period of observation, soils of clearcut plots had more moisture than those of undisturbed plots, while soils of thinned plots had an intermediate amount. Differences for the upper 24 inches of soil between clearcut and undisturbed plots ranged up to about 3.5 inches. Differences tended to be greatest in periods of high soil moisture and least at times of drought. After one prolonged drought, there was little difference in residual moisture among the three treatments.

Calhoun Experimental Forest, South Carolina.—Metz and Douglass (1959) studied soil-moisture depletion under several cover types in the Piedmont of South Carolina. Average annual precipitation in the area is about 48 inches. For a drying period of 40 days, the authors report soil-moisture losses in a 60-inch soil layer of about 2.9, 4.0, and 5.8 inches from barren, broomsedge, and pine plots, respectively.

Acknowledgment

THE evalution of treament effects in investigations of this kind depends as much upon the accuracy and dependability of daily measurements as upon the magnitude of the treatment effects themselves. For the decade of this study, Burley D. Fridley, forestry aide on the Fernow Experimental Forest, Parsons, West Virginia, maintained the instruments and installations and collected most of the basic records. Much of the success of this study can be attributed to his conscientious and efficient field work.

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EFFECTS OF SEEDBED, OVERSTORY, AND UNDERSTORY

ON

white ash regeneration

IN NEW HAMPSHIRE

by William B. Leak

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RALPH W. MARQUIS, DIRECTOR

EFFECTS OF SEEDBED, OVERSTORY, AND UNDERSTORY ON *white ash regeneration* IN NEW HAMPSHIRE

by William B. Leak

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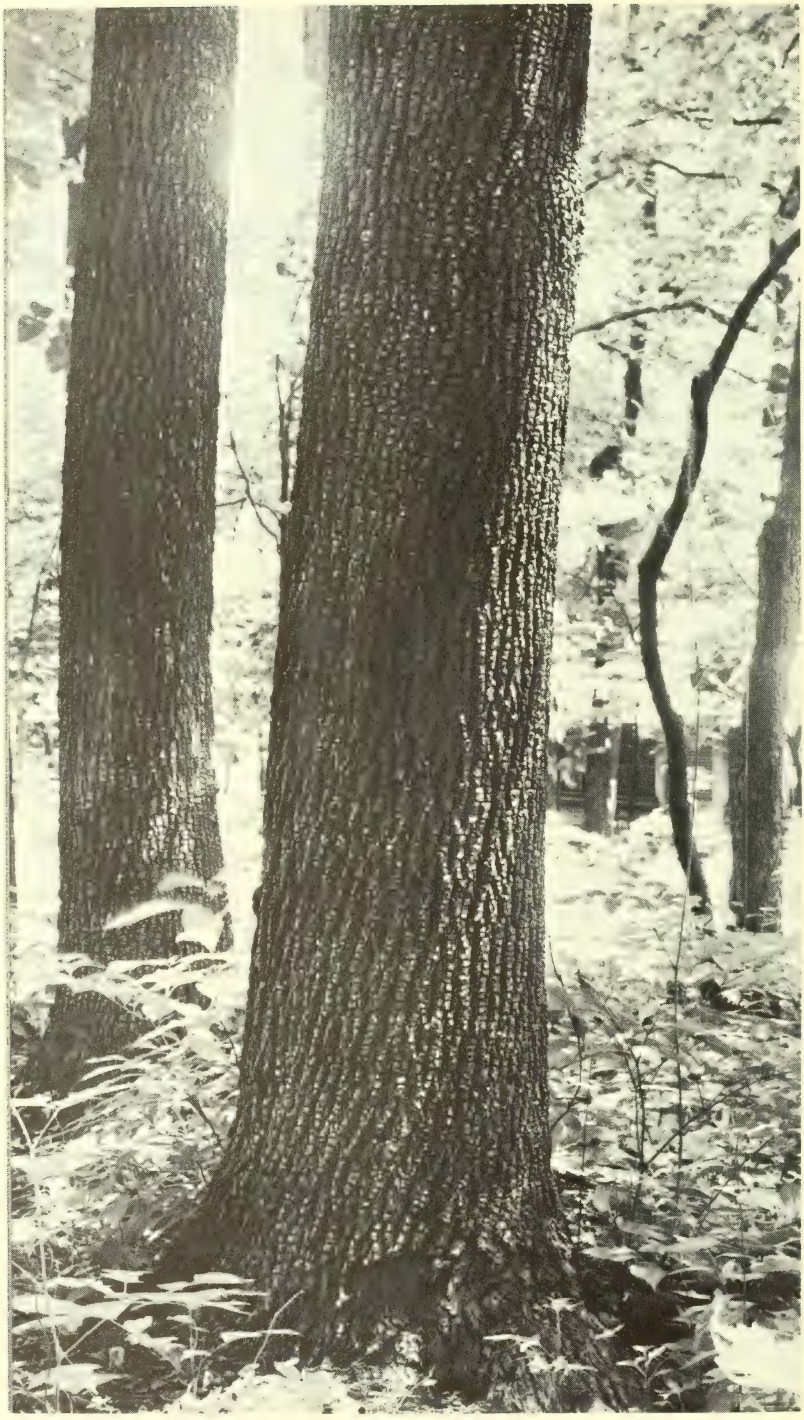
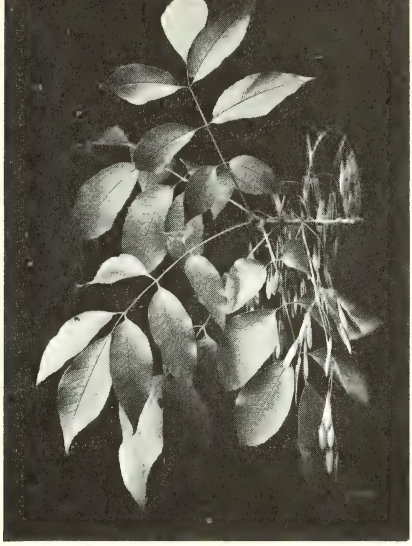
WILLIAM B. LEAK, *a research forester, received his Bachelor's degree in forestry from the State University of New York College of Forestry at Syracuse in 1953 and his Master's degree from the same institution in 1956. After joining the staff of the U. S. Forest Service Northeastern Forest Experiment Station in 1956, he served at the Experiment Station's research unit at Burlington, Vt., where he engaged in hardwood nursery and planting research; and at the research unit at Laconia, N. H., where he did research in northern hardwood silviculture. At present he is serving on the headquarters staff of the Experiment Station's Division of Forest Management Research, Upper Darby, Pa.*





A Species to Encourage

WHITE ASH (*Fraxinus americana*), although only a minor component of New Hampshire's northern hardwood forests, is one of the most desirable species in that forest type. Ash timber is in great demand for baseball bats, tool handles, and various other products in which toughness, elasticity, and resistance to impact are required. In bole form and growth rate, white ash compares favorably with most of its hardwood associates. Given the requisite silvicultural information, forest managers should encourage this species on the moist sites that apparently are most suitable for its growth and development.

However, not much is known about the silviculture of white ash. The little that is known has been learned largely through observation, or as a byproduct from studies of other species. Information is needed particularly on the natural regeneration of the species.[1] As a start toward meeting this need, a small study

[1] Wilson, Robert W. Jr., and Jensen, Victor S. REGENERATION AFTER CLEAR-CUTTING SECOND-GROWTH NORTHERN HARDWOODS. U. S. Forest Serv. Northeast. Forest Expt. Sta. Forest Res. Note 27, 3 pp., 1954.

of the establishment and early growth of white ash regeneration was started on the Bartlett Experimental Forest in New Hampshire in the fall of 1958.

The purposes of the study were twofold. First, we wished to determine how partial cutting and seedbed preparation in a forest stand affect the catch of white ash seedlings. (*Catch*, as used here, means the number of current-year seedlings alive at the end of the growing season.) Second, we wished to determine how partial cutting and undergrowth competition affect the growth of 1-year-old seedlings.

The Study Area

The area used for the study was occupied by an immature stand about 30 years old. Most of the stems were in the range of 3 to 12 inches d.b.h. (diameter breast high); only a few smaller saplings were present. The overstory was predominantly of red maple sprouts, among which were some scattered black cherry, paper birch, white pine, and balsam fir trees. The undergrowth consisted of a rather light cover of ferns, balsam fir seedlings, wild-raisin (*Viburnum cassinoides*), and miscellaneous other low plants.

The site over the entire study area appeared to be rather uniform. The topography was nearly level and without the mounds and depressions that are common under many New England stands. The soil was black with organic matter to a depth of 3 feet; this was underlain by a mottled sandy layer. Drainage was moderate to poor, but standing water was never found there during the growing season, even after a heavy rain. Since white ash in New Hampshire does best on moist sites, the area seemed to be a reasonably favorable one for this species.

There were no ash seed trees in the study area and nearby vicinity. This was fortunate in that it enabled us to keep close control over the seed supply. We could simply hand-sow study plots with given amounts of seed with assurance that no extra seed would blow in from other sources.

Treatments

Partial Cutting

To test the effects of three degrees of overstory density, three degrees of partial cutting were used. In the first, 40 percent of the basal area in trees over 2.5 inches d.b.h. was removed. In the second, 20 percent of the basal area was removed. The third was a control; here no cutting was done. The residual basal areas, in trees over 2.5 inches d.b.h., were respectively 63 square feet, 98 square feet, and 133 square feet.

Each cutting treatment was applied to one square 1/4-acre plot in October 1958. Dominant and codominant red maple sprouts, plus a few black cherry trees, made up most of the cut. All bolts and slash were removed from the plots by hand, so the ground was disturbed very little. In 1/2-chain-wide isolation strips around each plot, trees were girdled to simulate the same degree of cutting that was applied to the enclosed plot. Not all of the girdled trees died completely, but at least foliage density was greatly reduced.

Seedbed Preparation and Sowing

Three seedbed-preparation treatments were tested under each of the cutting treatments, as follows:

1. *Sown-scarified.* — Seeds were sown and then the ground was scarified, which mixed the seeds into the litter and surface soil material.

2. *Scarified-sown.* — The ground was scarified first and then seeds were sown.

3. *Undisturbed.* — Seeds were sown on undisturbed litter.

Scarification in treatments 1 and 2 consisted of chopping and mixing together the litter, surface humus, and some of the upper soil with a Rich fire tool.

These seedbed treatments were assigned at random to three 1/12-acre subplots within each of the three 1/4-acre cutting plots. Each subplot was sown with 2.8 pounds of fresh, uncleaned white

ash seed from the Bartlett Experimental Forest. This was about 23,300 seeds for each subplot, a rate of some 280,000 seeds per acre. All seedbed preparation and sowing was done immediately after the plots were cut in October 1958.

Understory Treatments

The main surge of germination did not occur until 1960, the second year after the seed was sown. In mid-June 1961, when these 1960 seedlings were 1 year old, three treatments were applied to the competing understory vegetation around selected sample seedlings of the 1960 crop. These treatments were:

1. Weeding. — All understory vegetation was completely removed around each sample seedling within a radius of 2 feet.

2. Bend and clip. — All understory vegetation taller than 6 or 8 inches within a radius of 2 feet from each seedling was pinned to the ground; smaller weeds and loose ends of pinned plants were clipped off at about two-thirds the height of the ash seedlings. This provided the sample seedlings with full light from above, except as shaded by the overstory, but reduced root competition relatively little. Some reduction in root competition occurred, of course, because of the clipping and other injuries, occasional mortality, and unavoidable interference with growth and transpiration of the bent-over plants.

3. Control. — All understory vegetation was left undisturbed.

Three groups of 15 seedlings each were selected in each 1/12-acre subplot, and the three understory treatments were assigned among seedling groups within subplots at random. Essentially constant competitive conditions were maintained through the 1961 growing season by re-treating as required at about weekly intervals.

When treated in June 1961 the ash seedlings averaged about 2½ inches tall, and had just begun to leaf out. The undergrowth was fairly light on the uncut plot but heavy on the partially cut plots. Heavy growth on the latter plots was to be expected, considering that two growing seasons had elapsed since cutting. This understory vegetation, consisting of cinnamon fern, raspberry, and several other species, averaged around 2 to 2½ feet in height.

Measurements

Numbers of seedlings were estimated at the end of the first and second growing seasons (1959 and 1960). For each estimate, two random strips of 14 milacres each across each subplot were tallied; this amounted to a 33.6-percent sample of the area. Strip locations in 1959 and 1960 were not the same. In 1960, 1-year and 2-year seedlings were tallied separately.

On the 405 seedlings where the competitive understory was treated, heights were measured immediately after treatment in June and again in September 1961. Measurements to the nearest 1/20 inch were taken between a black inkspot placed at the root collar and the tip of the stem or terminal bud. Also, in September, stem diameters $\frac{1}{2}$ inch above the root collar were measured to the nearest 1/64 inch with a micrometer.

Soil moisture, as a percentage of oven-dry weight, was determined from samples taken weekly from June 26 through August 28 in each understory-overstory treatment combination. Only the upper 3 inches of soil were sampled. Since the physical effects of the seedbed treatments had practically disappeared by 1961, this variable was not sampled. All samples were taken from the three sown-scarified subplots, which were assumed to be fairly representative of all subplots under each overstory condition. At each sampling, soil was taken separately adjacent to each of two seedlings in each of the nine understory-overstory treatment combinations—a total of 18 samples per week.

Results

Seedling Catch

A fairly good catch of white ash seedlings appeared in 1959, the first year after sowing. However, many more seedlings appeared in 1960 from seed that had remained dormant through the first year. This second-year catch varied among cutting treatments (all seedbed treatments combined) from about twice the first-year catch to five times as much; among seedbed treatments even greater differences occurred.

We cannot explain this seed dormancy; in fact, we are not sure whether such a high degree of delayed germination is characteristic of the species or is an unusual event. Nor can we explain why the ratio of second-year to first-year seed catch varied so much among cutting and seedbed treatments. A scattering of new germinates appeared on the study area during the summer of 1961 from seed that had lain dormant for 2 years. However, the

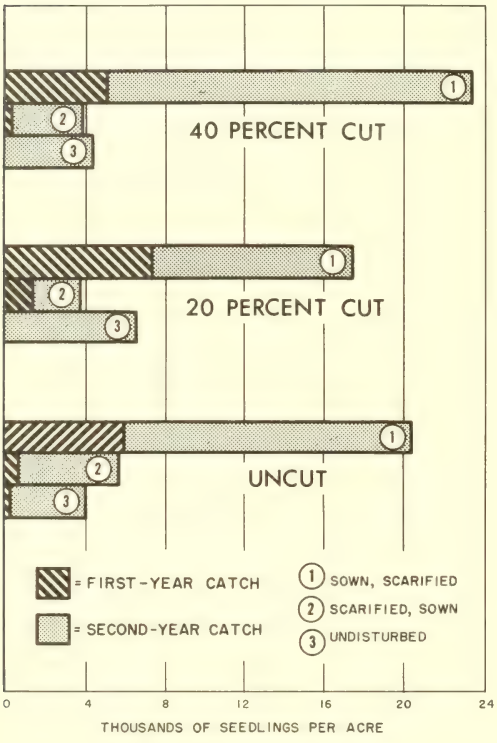


Figure 1. — Numbers of white ash seedlings per acre, showing effects of cutting intensity and seedbed treatment.

third-year catch was relatively small—no more than 500 to 600 trees per acre as compared to earlier catches running into the thousands. And since these seedlings were so far behind the advance growth, they stood little chance of coming through. Hence we have confined the following discussions to the first-year and second-year catches only.

The first-year catch varied with cutting treatment and seedbed treatment. Chi-square tests indicated that overall differences for both variables were highly significant (0.01 level). Among cut-

ting treatments (all seedbed treatments combined), the 20-percent cutting was best, followed by the uncut control and then by the 40-percent cutting. However, the differences among cutting treatments were not large enough to be of much practical importance. Among seedbed treatments, the sown-scarified treatment was by far the best, followed by the scarified-sown treatment and then by the undisturbed control (fig. 1).

The second-year catch also varied with cutting and seedbed treatments; overall differences again were highly significant. But the ranking of the cutting treatments now—as compared with the ranking for the first-year catch—was reversed: now the 40-percent cutting had the largest catch, and the 20-percent cutting had the smallest. Among seedbed treatments, the sown-scarified plot again had a far larger catch than the others (fig. 1).

Considering the first- and second-year catches combined, we can generalize on cutting and seedbed treatment results as follows: Differences among cutting treatments (all seedbed treatments combined), although significant at the 0.05 level, were not great enough to be of much practical importance. The ratio of numbers of seedlings was about. 1.1/1.1/1.0, respectively, for the 40-percent cutting, the uncut control, and the 20-percent cutting. Of the three seedbed treatments (all cutting treatments combined), the sown-scarified treatment produced by far the largest total catch; the ratio of numbers of seedlings was about 4.6/1.1/1.0 respectively for the sown-scarified, undisturbed, and scarified-sown seedbeds. Probably better coverage of the seeds with soil accounts for the larger catches with the sown-scarified treatment; this coverage undoubtedly provided a more plentiful and less variable moisture supply for stratification and germination than was available to uncovered seeds. Also, the covered seeds may have been exposed less to rodent damage.

Mortality

Although the study did not include a direct tally of mortality, differences between the estimated numbers of 1-year seedlings in the fall of 1959 and 2-year seedlings in the fall of 1960 provided some indication of mortality during that period.

Except for a loss of about 11 percent under the 40-percent cutting, mortality was low for all cutting and seedbed treatments. The greater losses under the 40-percent cutting possibly were due, at least in part, to higher air and soil temperatures than occurred under the heavier canopies. Small cankers that appeared to have been caused by excessive heat were found at the root collars of several seedlings.

Competition and Growth

The height-growth data presented here pertain only to growth that occurred on 1-year-old seedlings from mid-June, when the understory treatments were applied, to September of the same year. The figures thus do not represent total growth for the season.

The sample seedlings made relatively little height growth during the period of observation; averages by treatments were no more than ⅔ inch. However, some individual seedlings grew

Table 1. — Average height growth of 1-year white ash seedlings from mid-June to September, by overstory and understory treatments

Understory treatment	Percentage of overstory cut					
	40		20		0	
	Inches	*Percent*[1]	*Inches*	*Percent*[1]	*Inches*	*Percent*[1]
Weeding	0.39	14.1	0.61	22.0	0.24	9.2
Bend-and-clip	.42	17.6	.67	24.0	.26	10.7
Control	.19	7.7	.34	12.7	.14	6.1

[1]Growth percentages are based on heights at the start of the observation period in mid-June.

as much as 2 inches. Despite the small amount of average growth, several consistent or significant differences were evident.

Among cutting treatments, average height growth consistently was highest under the 20-percent cutting, intermediate under the

40-percent cutting, and lowest in the uncut stand. Growth in both inches and percentages—regardless of understory treatment—consistently followed this pattern (table 1). Since the cutting plots were not replicated, the figures are not well suited to statistical analysis, and one must be cautious in interpreting the data. But because the plots are so similar in topography, drainage, and soils, we believe that these growth differences must have resulted to a large extent from environmental differences induced by the cutting treatments.

Average height growth also varied with understory treatment. Height growth (in both percentages and inches) was roughly twice as much for the weeding and bend-and-clip treatments as for the untreated controls (table 1); and the differences were highly significant at the 1-percent level. The bend-and-clip treatment resulted in slightly but consistently more growth than the weeding, but differences between these two treatments were not significant.

By removing the undergrowth, the weeding treatment produced three changes in the seedlings' environment:

1. The seedlings were freed from competition for light (except from the overstory).

2. Losses of water through transpiration of the undergrowth were eliminated.

3. Evaporation from the ground surface probably was increased.

The bend-and-clip treatment also freed the seedlings from competition with the understory for light. But, in contrast to the weeding, the bend-and-clip treatment probably caused only slight to moderate changes in transpirational losses and evaporation from the ground. The fact that height growth under the weeding and bend-and-clip treatments was nearly the same implied that soil moisture under these treatments also was about the same; and this implication was confirmed by soil moisture determinations. Evidently increased evaporation from the bare soil in the weeding treatment just about balanced transpiration from the living plants in the bend-and-clip treatment.

The measurements of final stem diameter of ½ inch above the root collar indicated that height growth was not made at the expense of diameter growth. The cutting and understory treatments that produced the most rapid height growth tended to produce the largest or at least comparable diameters.

Soil Moisture

Soil moisture generally was higher under the 20-percent cutting than under the other two cutting treatments, except after mid-August when it dropped slightly below that of the other treatments. Soil moisture under the 40-percent cutting tended to be slightly but not substantially higher than under the uncut stand (fig. 2). Differences among the three understory treatments were small and inconsistent.

We cannot explain all the whys of the soil-moisture data, particularly why moisture under the 20-percent cutting ran higher than under the 40-percent cutting. Unrecognized variations in the content of organic matter possibly were involved. Since the

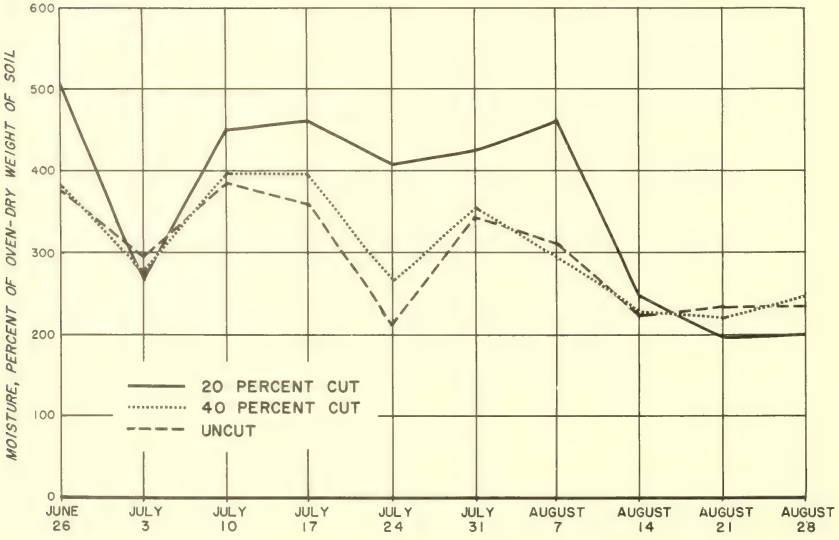


Figure 2. — Average soil moisture on the study plots in summer 1961. Based on oven-dry weight.

cutting treatments were not replicated, we cannot safely conclude that cutting intensity was responsible for the observed differences in soil moisture.

However, a noteworthy correlation occurred between soil moisture and seedling growth under the three cutting treatments: both moisture and growth were highest under the 20-percent cutting and lowest under the uncut stand. So, regardless of whether or not the higher soil moisture under the 20-percent cutting was a true effect of this cutting intensity, the higher moisture in conjunction with the moderate increase in light did produce the best height growth. Presumably the lower soil moisture under the 40-percent cutting was a limiting factor that prevented seedlings there from fully utilizing the stronger light available to them.

Discussion

Because this study was very limited in scope, we cannot offer any definite rules on how to regenerate white ash. But some information was acquired that should be of practical value to those who are interested in white ash regeneration. Until more information is available, our results should be considered applicable only on moist, highly organic soils in the White Mountains of New Hampshire.

The study results indicated that, to obtain a good catch of seedlings, the seeds should be well covered with soil. In practical woods operations, this might be accomplished by tractor-logging during late fall of a good seed year after seed dissemination, making sure that most of the ground is thoroughly disturbed by the skidding operations.

A substantial proportion of the ash seed in this study remained dormant over two winters before germinating. Since the seed was collected from only a few seed trees, we are not sure whether or not this extended dormancy is characteristic of the species. Until more information is available, surveys of the seedling catch on an area should be delayed until the end of the second growing season after seed dissemination.

The limited mortality, growth, and soil-moisture data all consistently indicated that removal of some of the overstory improved the environment for ash seedlings during their first 2 years of life, and that a comparatively light cutting (20 percent of the basal area) was better than a heavier (40 percent) cutting. Although observations were not extended beyond 2 years in this study, removal of considerably more than 20 percent of the overstory probably would favor growth of the ash seedlings after they were well established.

With opening of the overstory, herbaceous and shrubby understory vegetation was stimulated and became highly competitive with the ash seedlings. This competition was mainly for light. When the shading effect of the understory vegetation was eliminated, whether the competing plants were physically removed or merely bent aside, the growth response of the ash seedlings was about the same.

Our observations of understory competition point up the importance of avoiding or controlling this competition in field operations aimed at regenerating white ash. Unfortunately, our experimental treatments were not practical field treatments. Practical methods for coping with understory competition remain to be worked out.

Summary

A small plot study of the effects of partial cutting of the overstory, seedbed treatment, and understory competition on germination and early development of white ash seedlings was conducted in the White Mountains of New Hampshire. All plots were hand-sown with equal amounts of seed.

Because of extended seed dormancy, the catch of seedlings during the second growing season after sowing was considerably greater than the first-year catch, and a few seeds germinated during the third growing season after sowing.

Cuttings of 0, 20, and 40 percent of the overstory basal area had little effect on total seedling catch. Height growth of 1-year-old seedlings was stimulated to some extent by partial cutting,

and was rather consistently better under the 20-percent cutting than under the 40-percent cutting.

Scarification of the seedbed after sowing produced a much greater total seedling catch than pre-scarification or no seedbed treatment. Apparently covering of the seed with soil was highly beneficial to germination.

One-year-old seedlings that had been released from understory competition either by complete removal of the surrounding vegetation or by bending this vegetation down grew somewhat faster in height than unreleased seedlings. Soil moisture was not consistently altered by these treatments; the main limiting factor apparently was light.

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A survey of

Sawmill Residues and Lumber as Raw Materials

for wood-using industries in West Virginia

by Robert M. Frank

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A survey of

Sawmill Residues and Lumber as Raw Materials

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A LOOK AT OPPORTUNITIES

WEST VIRGINIA has long been a major producer of hardwood lumber. In 1960 about 275 million board feet of hardwood lumber were produced in the State. Other hardwood and softwood sawmill products accounted for an additional 145 million board feet. In all, 420 million board feet of sawmill products were sawed in West Virginia in 1960.

In contrast, other wood-using industries in the State are relatively undeveloped. There are a few secondary wood-using industries, such as flooring and furniture plants. And, besides sawmills, there are a few other primary wood-using plants that produce veneer and charcoal. However, there are no wood-pulp or particle-board plants.

Yet there are opportunities for the introduction and expansion of wood-using industries in West Virginia. Managers of firms in these industries and development agencies in the State are interested in knowing how good these opportunities are.

The availability and cost of materials to wood-using industries influence their opportunities for expansion. Lumber is needed for secondary industries, and sawmill residues can be an important source of material for some types of primary wood-using industries.

To evaluate the opportunities for development of wood-using industries in West Virginia, the Northeastern Forest Experiment Station of the U. S. Forest Service has made a study of the availability and cost of sawmill residues and lumber in West Virginia as raw material. Four areas in West Virginia were selected for evaluation: the Beckley, Elkins, Huntington, and Richwood areas (fig. 1). These areas have been suggested by forestry and economic development officials in West Virginia as four of the more favorable places in the State for expansion of wood-using industries.

Figure 1.—The four areas selected for study. In each case two areas were considered, one including the counties roughly within 25 miles of the city, the other counties roughly within 50 miles.

The reader should bear in mind that the data used in this report are based on a survey made in 1960. Since that time some changes have taken place in the industrial situation in West Virginia, including some changes in markets for wood residues and lumber. In general, though, the conclusions drawn from the survey are still relevant to the current situation.

LUMBER FOR FURNITURE AND FLOORING

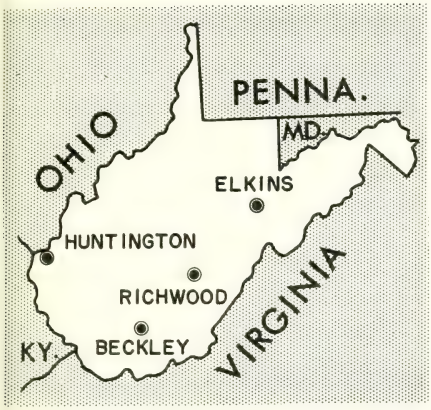
Two of the most important uses of hardwood lumber are for the production of flooring and furniture, including the production of dimension stock, which is used mainly for furniture. The evaluation of raw materials for new flooring and furniture plants depends largely on the present lumber industry in the State.

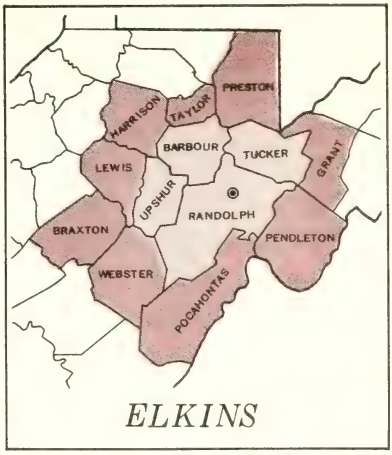
Sawmills in West Virginia are now producing at slightly less than two-thirds of capacity.[1] Approximately two-thirds of the sawmill production is sold to out-of-state markets. Of the volume utilized in West Virginia, about one-half (less than one-fifth of total sawmill output) is sold for remanufacture in flooring and furniture plants.

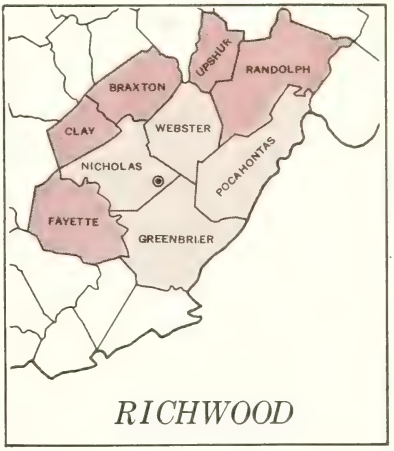
The flooring and furniture industries each require particular grades and species of lumber for use as raw material. At present, most hardwood floors in the United States are being constructed of red oak.[2] Lumber grades No. 2 and

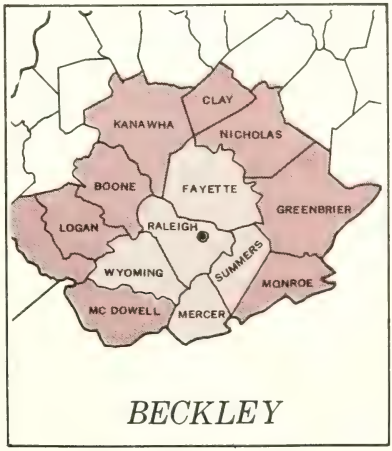
[1] Reid, W. H. and others. PRIMARY WOOD INDUSTRIES OF WEST VIRGINIA. W. Va. Univ. Agr. Expt. Sta. Bull. 461, 35 pp., 1961.

[2] Gregory, G. Robinson. A STATISTICAL INVESTIGATION OF FACTORS AFFECTING THE MARKET FOR HARDWOOD FLOORING. Forest Sci. 6: 123-134, 1960.









25-MILE AREA

50-MILE AREA

3A Common are used most widely in the manufacture of flooring. In furniture manufacture, the species and grade composition of the lumber used is broader. For this use the higher grades (FAS, No. 1, and No. 2 Common) of such woods as hard maple, yellow birch, black cherry, yellow-poplar, and the oaks are generally favored.

This evaluation of the availability and cost of lumber is made with respect to these particular requirements. However, the information presented here is also relevant for other lumber-using industries.

Volume

The volume of lumber production in all four areas is large enough to support remanufacturing facilities at a level substantially above the present level (table 1). In addition, appreciable quantities of ties and heavy mine materials are being produced. Sawmill production figures indicate that the volume of material produced as lumber[3] ranges from 66 percent of the total volume produced by sawmills in the Beckley area to 85 percent in the Huntington and Richwood areas. The total volume of lumber production is greatest in the Beckley and Richwood areas and smallest in the Huntington area.

Species

A major part of the total lumber production is made up of desirable species—oaks, yellow-poplar, hard maple, black cherry, and yellow birch (table 2). Oaks are the major species; they account for 36 percent of the total lumber production and 56 percent of the total production of sawed products other than lumber. Yellow-poplar is next; it makes up an additional 27 percent of the total lumber production. The northern hardwoods account for 15 percent. The species composition is similar for each of the four areas and is

[3] For purposes of this study lumber is defined as a sawmill product less than 4 inches thick.

favorable for supplying both the flooring and furniture industries.

The oaks and other hardwood groups make up a considerable proportion in the production of timbers (table 3). Only a minor part of the maple-cherry-birch group was reported as manufactured into timbers. However, because some of the small sawmills do not segregate production by species, it can be assumed that a part of the production reported for the other hardwoods group consists of these high-value species. Part of the material used in production of timbers is of high enough quality that it could be used in the production of flooring or furniture; this material is a potential source of raw material for remanufactuing.

Quality

Hardwood lumber quality in all four areas is suitable for use in remanufacturing (table 4). This is particularly true with respect to the oak flooring industry requirements. Furniture manufacturers have more demanding grade requirements; nevertheless, large quantities of No. 1 Common and Better lumber of the desired species are available. The lumber quality information in table 4 is based on the grade distribution of lumber only. One may assume that the proportion of material grading No. 2 Common and Poorer would have been greater—perhaps as much as 65 to 75 percent of the total—if all logs passing through the sawmill had been cut into lumber, since much of the structural material is produced from low-grade logs and portions of logs.

Availability

The size of the producing sawmill may affect the availability of lumber to potential buyers. Production of small sawmills is less stable than production from large mills. Small mills may be shut down for long periods each year, particularly during the winter months. Also, larger inventories enable the larger mills to carry a greater variety of species

and grades in substantial quantities. Over half of the lumber production in the Beckley and Richwood areas is from mills that produce more than 2,500,000 board feet per year (table 5). The remainder of the lumber production is about equally divided among the other mill-size classes. In general, ties and heavy mine materials make up a greater proportion of the total cut of small mills than they do at large mills.

Athough it is difficult to make price comparisons from the information that was obtained in this study, lumber prices in West Virginia appear to be competitive with prices in other parts of the Appalachian Region. Prices received in West Virginia (table 6) reflect uses and markets as of 1960. The location of new lumber-using plants in the State would probably have some effect on the lumber price structure.

SAWMILL RESIDUES FOR PARTICLE BOARD AND WOOD PULP

Increasing competition for raw materials has prompted many members of the wood-using industry to take a second look at the so-called wood-waste problem. *Wood residue* is the term now being used to describe the byproducts, such as slabs and edgings, that develop when round logs are converted into square-edged material. Opportunities for profitable utilization of these materials are now an alternative to disposal by burning or dumping.

Species, quantity, and cost of chippable sawmill residues are factors that would be considered by potential buyers of this material for use in producing particle board or wood pulp. Light-weight and light-colored species are generally used in particle-board production. Both the hard hardwoods and soft hardwoods are suitable for some pulping processes. Softwood sawmill residues can be used in both industries. However, at any one location, residues must be available in

sufficient quantities so that efficient handling methods may be used. Finally, the cost of this raw material to the mill must be low enough so it can compete with roundwood.

Volume

About 75 percent of the chippable sawmill residues produced in the four selected areas has been classified as hard hardwoods, about 20 percent as soft hardwoods, and about 5 percent as softwoods (table 7). Thus the volume available to the pulp industry is considerably greater than the volume available to the particle-board industry.

The volume of soft hardwood residues in all areas, with the possible exception of the Huntington area, appears to be sufficiently large to support moderately large-scale particle-board production. However, the volume of residues does not appear to be large enough in any of the areas to support entirely a major pulping facility. Yet, the volume in all areas—again with the possible exception of the Huntington area—is large enough to be considered a major source of raw material to a pulp mill that also uses pulpwood obtained in round form.

Availability

Disposition of chippable sawmill residues—including slabs, edgings, trim, and cull lumber—was as follows in West Virginia in 1960:

	Percent
Not utilized—burned	53
Not utilized—dumped	2
Given away for fuel	4
Given away for manufacture into products	1
Sold for fuel	15
Sold for manufacture into products	12
Used by mill as fuel	12
Used by mill for manufacture into products	1
Total	100

This tabulation shows that direct income was received for only 27 percent of the residues that were produced. About

one-half of this amount was sold for use in charcoal manufacture; a small quantity was sold for use in the ceramic and metallurgical industries. Most residues sold for fuel were purchased for home use—and no expansion of this market is likely. If the 12 percent of the residues used for fuel at the sawmill were sold for other uses, the sawmills would incur a replacement cost for the equivalent in other fuels.

The remaining 60 percent of the residues produces no income for the sawmill owner. In fact, this material still creates a disposal problem. (As shown in the tabulation, 5 percent of the total was given away, which results in an elimination of removal costs and a reduction in fire hazard.) Thus, fairly large quantities of chippable residues would probably be available to new industries in all four areas.

The attractiveness of this supply of residue to potential buyers depends in part on the volume that is available at individual sawmill locations. Sawmills in the largest size class in the Beckley and Richwood areas use nearly half of their production of residues for fuel (table 8). This still leaves, at mills in this size class, substantial quantities that are not utilized or are given away. For all other mill-size classes and areas, the majority of the residues are not now utilized. Stability of supply to the purchaser should not be a problem.

Prices

Prices reported for residues were highest in the Elkins area (table 9). This is probably due to the established charcoal industry in this area. Prices received in other areas were fairly uniform. Differences in reported prices reflect in part services such as cutting-to-length, bundling, and loading. The introduction into these areas of new markets for this material would change the present price structure. For example, material now being used as fuel at the sawmill might be made available for other uses if markets were present. Based on the 1960 structure, prices as low as $1 per ton would enable purchasers to compete for more than half of the total volume of residues.

SUMMARY

The availability and cost of sawmill residues and lumber as raw material in West Virginia are generally favorable for expansion of wood-using industries in the State. Raw-material requirements indicate that there are several opportunities for new flooring and furniture plants that would use lumber produced within the State and for new particle-board and wood-pulp mills that would utilize sawmill residues.

Substantial volumes of lumber from a number of commercially important hardwood species are now being produced in West Virginia. This lumber, a high proportion of which is now being shipped out of the State, could provide raw material for new flooring or furniture plants in West Virginia. Lumber quality and availability are favorable for new plants.

Large volumes of sawmill residues, which could be used in the production of wood pulp or particle board, are produced within the State. Volumes are sufficient to supply new particle-board plants with all necessary raw materials and to supply new wood-pulp mills with an important part of their raw-material requirements. Sixty percent of this material was not being sold or utilized by the sawmills. This material presumably would be available for new plants.

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APPENDIX

I. METHOD OF CONDUCTING SURVEY

Scope

Estimates of lumber and residue production are based on the production of sawmills in the four selected areas in 1960. The selected areas include the counties within approximately 25-mile and 50-mile radii of four towns in West Virginia—Beckley, Elkins, Huntington, and Richwood. The Huntington area includes adjacent sections of Ohio and Kentucky.

Selecting the Sample

The population from which the sample was drawn constituted all sawmills located in the four areas.[4] The list of sawmills was stratified by sawmill size classes. Sample mills were selected at random within each stratification. The proportion of sample mills is greatest in the larger size classes and smaller in the smaller size classes. The total size of the sample was 111 sawmills, including 11 each in Ohio and Kentucky. The 89 mills sampled in West Virginia produced approximately one-third of the volume produced in the State (based on 1957 figures) and accounted for less than 15 percent of the total number of active mills in the areas sampled.

Obtaining the Estimates

Operators of the sample sawmills were interviewed during the summer of 1961 to obtain information on 1960 production. The information obtained in the interviews included production figures, hardwood lumber quality, residue disposition, and lumber and residue prices.

A 1957 canvass of sawmills in West Virginia conducted by the West Virginia Conservation Commission in cooperation with West Virginia University was used as a basis for obtaining 1960 estimates of production. Total 1960 sawmill production in the selected areas in West Virginia was estimated by revising 1957 estimates upward to 1960 on the basis of the present sample of mills. Production figures for counties in Ohio and Kentucky included in this survey are based only upon 1960 information from the sample mills in the area. These figures were expanded on the basis of the proportion of the number of sample mills in each size class to the total number of mills in each size class in these counties. Production classes, based on mill production in 1957, were defined as follows:

Class	*Production (1,000 board feet)*
I	Less than 500
II	500 to 999
III	1,000 to 2,499
IV	2,500 and more

[4] McCauley, Orris D., and Quigley, K. L. MARKETS FOR OHIO TIMBER. U. S. Forest Serv. Central States Forest Expt. Sta. Misc. Release 14, 53 pp., 1957. Also Division of Forestry, West Virginia Conservation Commission DIRECTORY OF SAWMILL OPERATORS IN WEST VIRGINIA, 54 pp., 1959; and unpublished listing prepared by Kentucky Division of Forestry, 1960.

Distribution of species was based on the 1957 canvass. Lumber grade distribution was determined on the basis of 1960 sample mill data. Estimates of grade distribution were obtained for the 50-mile areas; these estimates were then applied to lumber-production figures for the 25-mile areas. Estimates of sawmill output going into lumber and timbers was also based upon 1960 sample-mill data.

Quantities of chippable residue produced were based on estimates of sawmill production. Necessary conversion factors were obtained from a study conducted in Maryland, but based on species similar to those found in West Virginia.[5]

[5] Simmons, Fred C., and Bond, A. R. SAWMILL WASTE IN MARYLAND. U. S. Forest Serv. Northeast. Forest Expt. Sta., Sta. Paper 74, 31 pp., illus., 1955.

II. TABULAR DATA

Table 1.—*Production of lumber and timbers, 1960*
(In millions of board feet)

Area	Product		
	Lumber	Timbers[1]	Total
Beckley			
Within 25-mile area	70	31	101
Within 50-mile area[2]	155	79	234
Elkins			
Within 25-mile area	35	7	42
Within 50-mile area	95	23	118
Huntington			
Within 25-mile area	13	3	16
Within 50-mile area	46	8	54
Richwood			
Within 25-mile area	77	14	91
Within 50-mile area	144	28	172

[1] Ties, mine timbers and other timbers, dimension stock, and miscellaneous sawmill products 4 inches thick and thicker.

[2] Volumes for 50-mile area include volumes for 25-mile area. Areas are defined to include counties within roughly 25 miles and 50 miles of the central towns. Because parts of the areas overlap, the figures are not cumulative.

Table 2.—*Lumber production by species groups, 1960*[1]
(In millions of board feet)

Area	Red oaks	White oaks	Poplar, basswood, cucumber	Maple, cherry, birch	Other hardwoods	Softwoods	All species
Beckley							
25-mile area	16	8	19	7	11	9	70
50-mile area[2]	36	18	41	22	22	16	155
Elkins							
25-mile area	9	3	10	6	7	([3])	35
50-mile area	25	11	23	15	15	6	95
Huntington							
25-mile area	3	2	3	2	3	([3])	13
50-mile area	14	4	16	3	7	2	46
Richwood							
25-mile area	14	9	14	19	9	12	77
50-mile area	31	16	36	28	18	15	144

[1] Sawmill products less than 4 inches thick.
[2] Volumes for 50-mile area include volumes for 25-mile area.
[3] Less than 500,000 board feet.

Table 3.—*Production of timbers, by species groups, 1960*[1]
(In millions of board feet)

Area	Red oaks	White oaks	Poplar, basswood, cucumber	Maple, cherry, birch	Other hardwoods	Softwoods	All species
Beckley							
25-mile area	10	6	3	1	10	1	31
50-mile area[2]	27	15	8	3	24	2	79
Elkins							
25-mile area	4	1	(3)	1	1	(3)	23
50-mile area	10	5	1	2	3	2	23
Huntington							
25-mile area	1	1	(3)	(3)	1	(3)	3
50-mile area	3	1	(3)	(3)	3	(3)	8
Richwood							
25-mile area	5	3	1	1	3	1	14
50-mile area	12	6	2	1	6	1	28

[1] Ties, mine timbers, and other timbers, dimension stock, and other miscellaneous sawmill products 4 inches thick and thicker.
[2] Volumes for 50-mile area include volumes for 25-mile area.
[3] Less than 500,000 board feet.

Table 4.—*Hardwood lumber production, by grades,*[1] *1960*
(In millions of board feet)

Area	FAS, FAS-IF, saps, and selects	No. 1 Common	No. 2 Common and Poorer	All classes
Beckley				
25-mile area	10	20	31	61
50-mile area[2]	24	46	69	139
Elkins				
25-mile area	5	9	21	35
50-mile area	11	22	56	89
Huntington				
25-mile area	2	3	8	13
50-mile area	6	11	27	44
Richwood				
25-mile area	11	20	34	65
50-mile area	22	39	68	129

[1] Includes lumber that was not graded. Grade distribution of ungraded lumber based on information from concentration yards included in sample.
[2] Volumes for 50-mile area include volumes for 25-mile area.

Table 5.—*Sawmill production by products and mill-size class, for 50-mile areas, 1960*
(In millions of board feet)

Area and product	Mill size class, in 1,000 board feet				All classes
	Less than 500	500-999	1,000-2,499	2,500 or more	
Beckley					
Lumber	31	27	15	82	155
Timbers	12	24	37	6	79
Elkins					
Lumber	22	15	32	26	95
Timbers	7	6	6	4	23
Huntington					
Lumber	16	5	21	4	46
Timbers	3	2	2	([1])	8
Richwood					
Lumber	34	18	12	80	144
Timbers	8	2	14	4	28

[1] Less than 500,000 board feet.

Table 6.—*Lumber prices for selected hardwood species and grades, 1960*

(Dollars per 1000 board feet)
(Basis: f.o.b. sawmill, 4/4-inch rough, green to air-dry)

Species	Grade class				
	FAS, FAS-IF, saps, and selects	No. 1 Common	No. 2 Common	No. 2 Common and Poorer	No. 3 Common and Poorer
Red oak					
Range	144-197	91-101	55-64	..	30-54
Average	163	95	58	..	40
White oak					
Range	155-220	86-111	53-64	..	30-54
Average	174	92	57	..	40
Hard maple					
Range	218-247	143-162	..	56-74	..
Average	228	151	..	65	..
Black cherry					
Range	238-281	160-190	..	61-92	..
Average	254	175	..	79	..
Yellow-poplar					
Range	151-184	103-121	..	61-76	..
Average	162	110	..	64	..
Beech					
Range	130-143	101-113	..	46-58	..
Average	137	109	..	52	..

Table 7.—*Production of chippable residues, by species group, 1960*[1]
(In thousands of tons, oven-dry)

Area	Hard hardwoods	Soft hardwoods	Softwoods	All species
Beckley				
25-mile area	50	14	4	68
50-mile area[2]	117	31	9	157
Elkins				
25-mile area	22	6	([3])	28
50-mile area	61	14	4	79
Huntington				
25-mile area	10	2	([3])	12
50-mile area	26	9	1	36
Richwood				
25-mile area	40	9	6	55
50-mile area	81	22	7	110

[1] Slabs, edgings, trim, and cull lumber.
[2] Volumes for 50-mile area include volumes for 25-mile area.
[3] Less than 500 tons.

Table 8.—*Production of chippable residues*[1] *by mill-size class and present use class, 1960*
(In thousands of tons, oven-dry)

Area[2] and mill-size class (in 1,000 board feet)	Present use class			
	Given away or not utilized	Sold	Burned as boiler fuel or manufactured into products	All classes
Beckley				
Less than 500	4	25	([3])	29
500-999	24	10	([3])	34
1,000-2,499	23	11	1	35
2,500 or more	24	4	30	58
Elkins				
Less than 500	13	6	1	20
500-999	8	5	([3])	13
1,000-2,499	18	8	([3])	26
2,500 or more	16	([3])	4	20
Huntington				
Less than 500	11	2	([3])	13
500-999	4	1	([3])	5
1,000-2,499	13	2	([3])	15
2,500 or more	3	([3])	([3])	3
Richwood				
Less than 500	21	6	([3])	27
500-999	5	7	1	13
1,000-2,499	11	6	([3])	17
2,500 or more	26	7	21	54

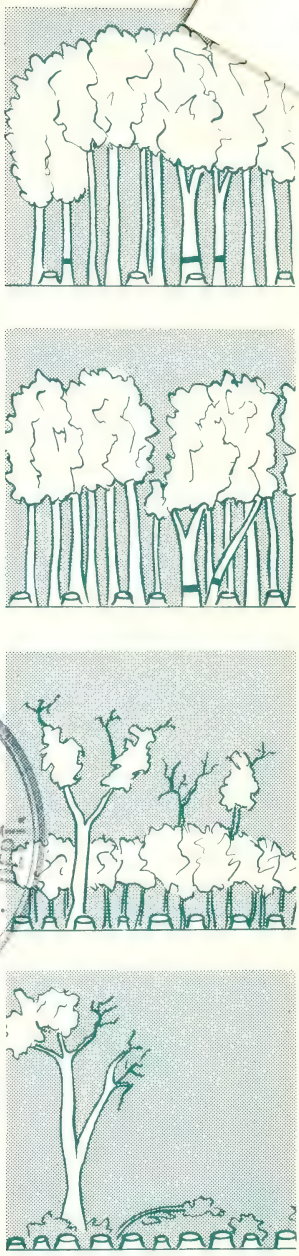
[1] Slabs, edgings, trim, and cull lumber.
[2] 50-mile areas.
[3] Less than 500 tons.

Table 9.—*Residue price ranges and averages, 1960*
(Basis: f.o.b. sawmill, green)

Area	Unit of measure	Price (in dollars)	
		Average	Range
Beckley	Ton	1.50	0.60-4.00
	Standard cord	3.00	1.50-4.00
Elkins	Ton	1.75	1.00-2.00
	Standard cord	4.00	.50-15.00
Huntington	Ton	2.00	1.00-10.00
	Standard cord	2.50	1.25-3.50
Richwood	Ton	1.25	.60-3.00
	Standard cord	2.50	.50-4.00

A Demonstration of **FOUR INTENSITIES OF MANAGEMENT** in Northern Hardwoods

by
Barton M. Blum
Stanley M. Filip



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NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
RALPH W. MARQUIS, DIRECTOR

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A Demonstration of **FOUR INTENSITIES OF MANAGEMENT** in Northern Hardwoods

History

MORE than 10 million acres of land in New England are classified as northern hardwood forests.[1] The increasing importance of these beech-birch-maple forests to the economy of the region emphasizes the need for better guides to good management of northern hardwood forests.

High-quality northern hardwoods, particularly sugar maple and yellow birch, have always been in some demand in the Northeast for furniture and specialty products. In the early days inaccessibility of the better timber, difficulties in handling and transporting the heavy hardwood logs, and limited markets prevented better utilization. Except for fuelwood, only the best and most accessible hardwood timber was exploited. By 1950, however, improved technology in logging and transportation, together with the opening of new markets in the veneer and pulp industries, had changed the picture. Heavy equipment and extended road systems had by then lessened the problems of transportation and log handling. The demand for logs for high-grade veneer had grown rapidly, and somewhat later the paper industry had begun to

[1] United States Forest Service. TIMBER RESOURCES FOR AMERICA'S FUTURE. U. S. Dept. Agr. Forest Resource Rpt. 14, 713 pp., illus., 1958.

utilize hardwoods for pulp. Today there is an increased demand for all species of hardwoods; and the demand for large, high-quality logs often exceeds that for many softwoods.

Ironically, it is this increased demand that has led to our present problems in old-growth northern hardwoods, because increased demand has forced us to face the task of rehabilitating these long-neglected forests and stepping up their production in both quantity and quality. Look back a few decades and see what has happened. At the turn of the century most of the northeastern forests were cut over for the first time, and only the best softwoods were taken. Next, as the demand for hardwood lumber increased, the best of the hardwoods were cut. The trees left behind are now the old veterans, usually mixed with young and vigorous recruits that either were present but unmerchantable when the stands were first cut or came in later. This is the so-called typical old-growth northern hardwood forest now found in New England—large volumes of overmature timber, poor in quality and vigor, but interspersed with many young, sound trees.

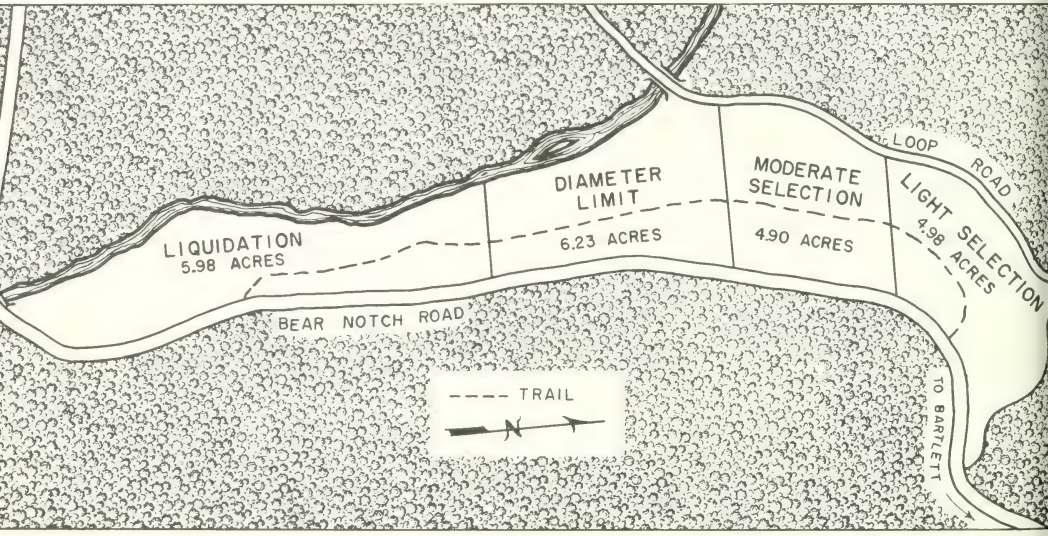


Figure 1.—Plan of the demonstration plots on the Bartlett Experimental Forest.

It is in old-growth stands of this sort that U. S. Forest Service researchers at the Bartlett Experimental Forest, in Bartlett, New Hampshire, have established large-scale studies to provide needed information on northern hardwood management practices. To enable interested visitors to see some of these management practices more conveniently, four small demonstration plots have been established on the Forest (fig. 1). This paper describes those plots and points out their efficacy and value as demonstrations of four specified management programs.

What Is Being Demonstrated?

The management practices demonstrated on the four plots represent the basic management-intensity levels under test in the large study at Bartlett; they also exemplify the different management intensities to be found today in the northern hardwood region.

Method of cutting is the basic component of any program or system of management practices concerned with harvesting and regenerating a timber stand. To a large degree, the method of cutting determines what other practices or cultural measures are possible or feasible. In the general discussion that follows, the basic elements of the cutting methods demonstrated and their advantages and disadvantages are described.

Methods of Cutting

Only three methods of cutting are represented on the four plots. The method discussed first — single-tree selection — was applied according to different specifications on two plots; the other two methods were used on one plot each.

Single-tree selection.—Foresters have long observed that the single-tree selection system of cutting is well adapted for most old-growth northern hardwood stands. This method usually results in the most efficient use of the productive capacity of the

land. It is flexible: the forester can keep individual trees for further growth and development, and he can mark others for removal—using tree vigor, amount of defect, and spacing as the major criteria. Since the amount of timber removed under this method usually is small compared to other cutting methods, the time between successive cuttings is relatively short. And, because of this shorter cutting cycle, tree mortality should be at a minimum: low vigor trees that would die over longer cutting cycles are salvaged.

Past experience in old-growth northern hardwood management, as well as trends observed in current studies, indicate that this cutting method has further advantages. It will, for instance, provide income for an owner at fairly short intervals while improving, and later maintaining, timber quality. It permits development and maintenance of a balanced size-class distribution in the growing stock (those trees retained to grow and develop). Moreover, this is the most widely accepted cutting method for watershed management and for aesthetic values.

But there are disadvantages. An owner may have a large investment tied up in his timber that is subject to risk because of fluctuating markets and such natural hazards as fire, wind, insects, and diseases. Then, too, this system tends to perpetuate the shade-tolerant species, which may not always be desirable.[2]

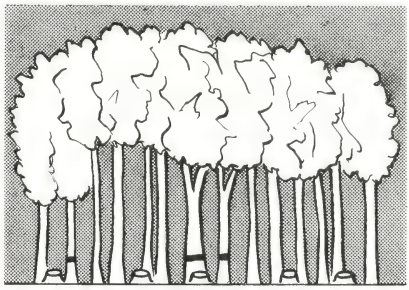
Diameter limit.—The diameter-limit method of cutting, in its simplest form, disregards both species and tree quality; all trees over a minimum size are taken. Consequently, cuttings made by this method usually do not improve the growing stock because many defective trees are left in the lower diameter classes. On the other hand, vigorous, well-formed trees in the larger classes that might greatly increase in value by the time of the next cutting are removed. The length of the cutting cycle will depend on the minimum diameter used.

---

[2] Tolerant species: beech (*Fagus grandifolia* Ehrh.), sugar maple (*Acer saccharum* Marsh.), hemlock (*Tsuga canadensis* L. Carr.), and red spruce (*Picea rubens* Sarg.). Intolerant or intermediate (those that require direct sunlight): paper birch (*Betula papyrifera* Marsh.), yellow birch (*B. alleghaniensis* Britton), white ash (*Fraxinus americana* L.), red maple (*Acer rubrum* L.), and aspen (*Populus tremuloides* Michx. and *P. grandidentata* Michx.)

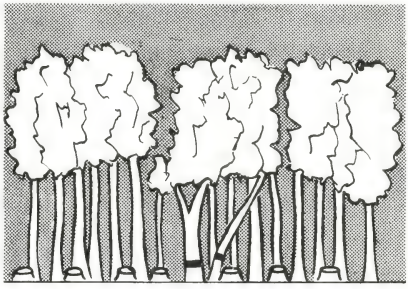
LIGHT SELECTION
4.98 acres

Basal area, square feet	
Original:	128.4
Harvested:	23.1
Girdled:	10.5
Residual:	94.8
Removed:	26%



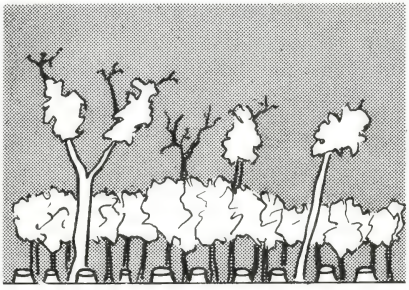
MODERATE SELECTION
4.90 acres

Basal area, square feet	
Original:	123.6
Harvested:	34.2
Girdled:	6.7
Residual:	82.7
Removed:	33%



DIAMETER LIMIT
5.23 acres

Basal area, square feet	
Original:	117.9
Harvested:	45.3
Girdled:	8.7
Residual:	63.9
Removed:	46%



LIQUIDATION
5.98 acres

Basal area, square feet	
Original:	122.5
Harvested:	84.4
Girdled:	—
Residual:	38.1
Removed:	69%

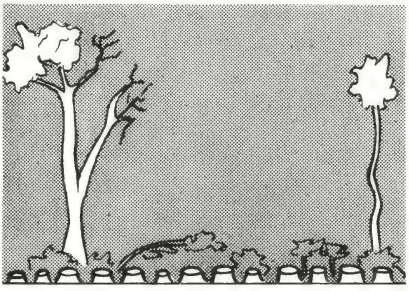


Figure 2.—Specifications for the Management· Intensity Demonstration Plots. Basal-area figures are in square feet per acre for trees 4.5 inches d.b.h. and larger.

Experience with the diameter-limit method of cutting has shown that ordinarily it will provide a larger income from the first cutting than the single-tree selection system. The landowner will materially reduce his investment in standing timber. Handling costs will be lower and the logging will be more attractive to operators because, volume for volume, the average size of the trees cut will be larger than under the selection system. Average quality of the products will be higher because, other things being equal, the larger trees and larger logs yield a larger percentage of high-grade lumber. A further advantage is the ease with which diameter-limit cutting can be applied.

Opposed to these advantages are several serious disadvantages. The general quality of the residual growing stock is lowered by diameter-limit cutting; the next cutting is likely to yield less quality material than the first cutting, whereas under the selection cutting the growing stock and product quality improve with successive cuttings. Residual stands after diameter-limit cutting often are irregular, with some portions well stocked and others practically clearcut. Aesthetic values are altered, usually adversely. Under diameter-limit cutting an individual woodlot or stand yields income only at relatively long intervals; at least 20 to 30 years ordinarily must elapse after the first cutting before another cutting of similar volume can be made.

Liquidation.—This is a commercial clearcutting that removes all merchantable products—ordinarily a very heavy cutting. The residual stand will vary according to the products the local market will accept and the product objectives of the operator.

On the surface, a liquidation cutting seems to have few advantages. However, it may be the best course to take in stands with poor growing stock or in relatively inaccessible stands where road construction costs are high. Or, for various reasons, an owner may need to convert his investment into ready cash. Then too, the first liquidation cutting in old-growth northern hardwoods usually leaves conditions favorable for regeneration of the more valuable intolerant species.

Among the disadvantages are the long time required for another merchantable stand to develop, and the temporary re-

duction of aesthetic values. Perhaps the greatest disadvantage is the removal of prime, fast-growing trees that are just beginning to produce high-value wood.

All three cutting methods discussed have some advantages, and some disadvantages. The choice of cutting method will be determined largely by the landowner's management objectives, as governed by economic and aesthetic considerations. The practicability of attaining these objectives will be affected in turn by site, accessibility, and general stand conditions.

The Demonstration Plots

It was for the purpose of demonstrating several distinctly different management practices, based upon the methods of cutting described above, that the four Management Intensity Demonstration plots were established. Two of the practices, or management intensities, were based upon single-tree selection cutting —one representing a light cutting and one a moderate cutting. The third intensity was based upon diameter-limit cutting and the fourth upon liquidation cutting.

The demonstration plots are approximately 5-acre stands situated on a gentle to moderately steep northerly slope. The very stony soils are derived from glaciated material. Early hardwood logging removed the best of the sugar maple and birch and left a high proportion (nearly half) of beech in the residual stands. Besides the beech, other major species growing on the plots included sugar maple, yellow birch, and eastern hemlock, with lesser amounts of paper birch, white ash, red maple, aspen, and spruce. Before treatment the stands were uneven-aged, with relatively young saplings and poles growing among sawtimber trees, some several hundred years old. Seedlings of the tolerant species were plentiful, and the tolerants made up a large proportion of the growing stock in all size classes.

The Treatments

The first step was to inventory all trees at least 4.5 inches in diameter at breast height (4.5 feet from the ground) to determine the volume of wood on each plot. Then the plots were

logged, each according to one of the methods of cutting previously described (fig. 2). This was done in 1952. Reinventories were made immediately after logging and again in 1959 in order to obtain growth and mortality data.

In addition to the harvest cutting, some unmerchantable trees in the plots treated by selection and diameter-limit cuttings were eliminated by girdling. This work, done in 1953, raised the average quality and vigor of the growing stock by ridding the stand of poor quality trees, released potentially merchantable trees, and provided growing space for reproduction.

The light selection plot.—On this plot trees were marked for either cutting or girdling. In keeping with the above-described criteria of the single-tree selection system, a short cutting cycle—5 to 7 years—was prescribed, with a growing-stock level objective of 100 square feet of basal area[3] per acre to be retained after each cutting. This means a comparatively heavy residual stand will be maintained. More unmerchantable trees were girdled on this plot than on any of the others.

A second cutting was made, as scheduled, on this plot in 1959. However, no data from this second cutting are included in this report.

The moderate selection plot.—The treatment on this plot was similar basically to that on the light selection plot; it differed in that less cultural work (girdling) was done, and the prescribed cutting cycle was 10-15 years, with a somewhat lower growing-stock level objective—80 square feet of basal area per acre. Figure 3 illustrates the types of trees cut and girdled on both selection plots.

The diameter-limit plot.—Again in keeping with the specifications for this cutting method, trees on this plot were not marked individually; instead, all merchantable trees larger than

[3] Basal area is the area of the cross section of a tree measured at breast height (4.5 feet from the ground) and expressed in square feet. As a unit of stand measurement, it commonly is expressed as square feet per acre. Unmanaged stands of old-growth northern hardwoods at Bartlett will reach a maximum basal area per acre of about 125 to 130 square feet. For converting to cubic feet or board feet, 1 square foot averages 23 cubic feet; or, for sawtimber trees only, 1 square foot is equivalent to about 140 board feet (International ¼-inch log rule).

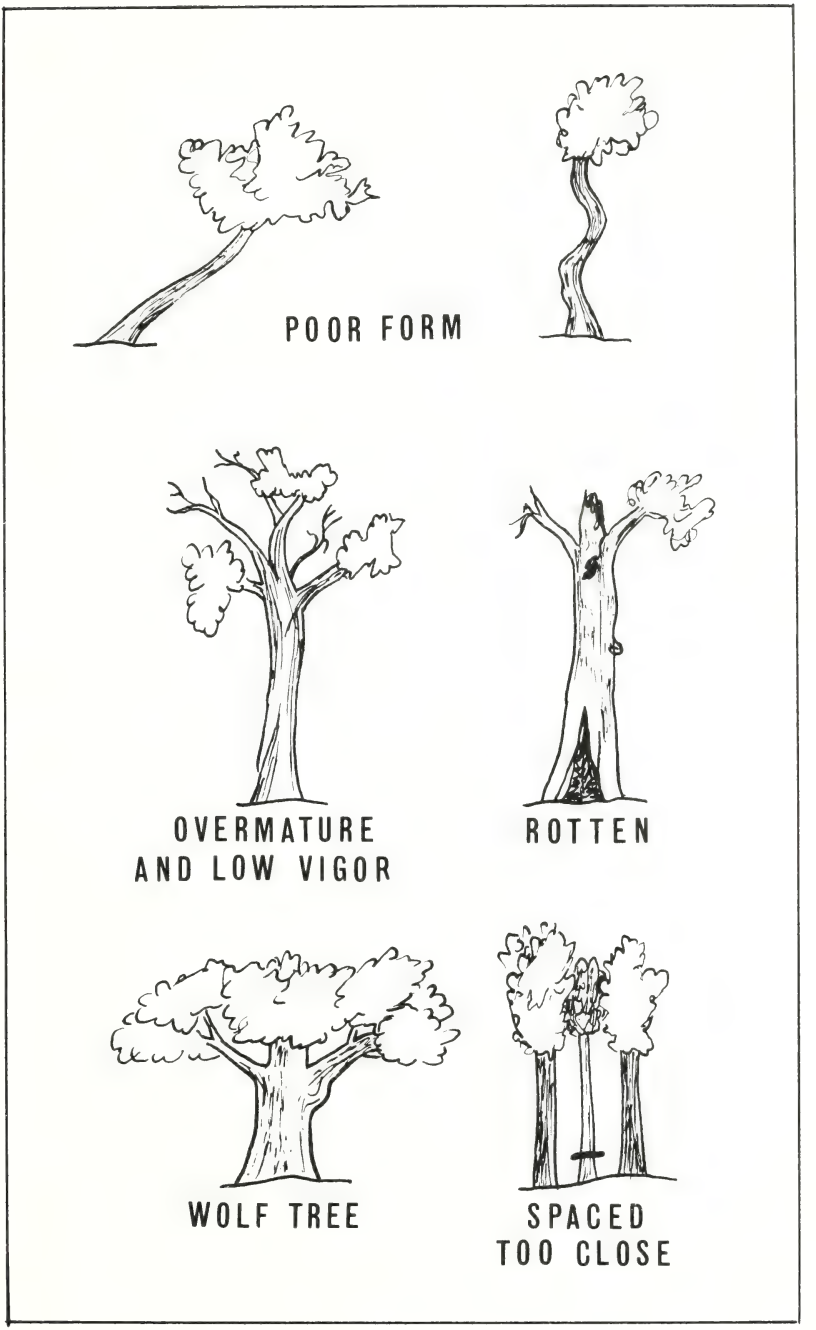


Figure 3.—The types of trees marked for cutting and girdling on the selection plots.

14.5 inches in diameter were cut by the loggers. The growing-stock level objective is 60 square feet of basal area per acre after each cutting, and the cutting cycle is estimated at 20 to 30 years. A cutting cycle of this length will not produce future cuttings with as large trees as in the initial cutting.

Some of the cull trees left by the loggers on this plot were girdled. Girdled trees were all larger than the diameter limit of 14.5 inches and were removed only if they interfered with reproduction or competed with promising trees.

The liquidation plot.—On this plot, cutting removed all merchantable products, including pulpwood. No girdling of cull or wolf trees was done to improve the residual stand. Another commercial cutting will not be possible until a new stand has developed.

On both selection plots, logging roads were located only on gentle grades, and water bars were installed at the end of the job to prevent soil erosion and gullying. Logging damage to the residual stands was minimized by avoiding sharp turns in laying out skid-trails, and by close supervision of the logging. No such measures were taken on the diameter-limit and liquidation plots.

Validity of the Demonstrations

For the Management Intensity Demonstration plots to fulfill their primary objective as demonstrations, the treatments used on the plots must be valid examples of the four specified intensities of management and, particularly, of the cutting methods on which they are based. The 7-year results presented below show that the treatments have exemplified those management intensities reasonably well.

Stand Growth and Quality

The important factors in the evaluation of any management practice are the quantity of wood produced, the quality of that wood, and the degree of success attained in perpetuating desired

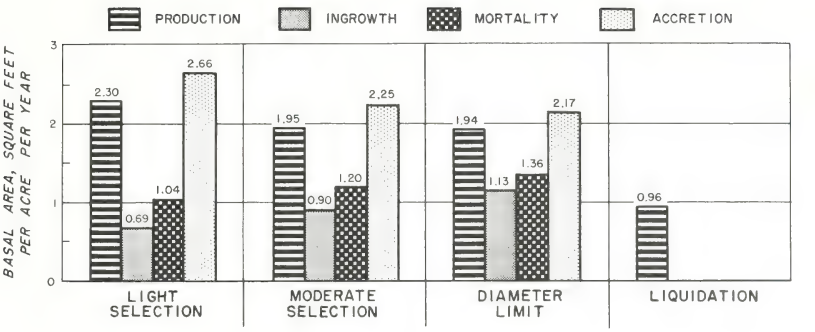


Figure 4.—Growth data for the demonstration plots, based on 100-percent inventories of all trees 4.5 inches d.b.h. and larger.

species. To aid in evaluating the treatments used on the demonstration plots, the growth data are presented in figure 4. The terms used are defined as follows:

Accretion is the growth on those trees in the residual stand that were large enough to be measured in the inventory taken immediately after logging; that is, all trees 4.5 inches and larger in diameter at breast height.

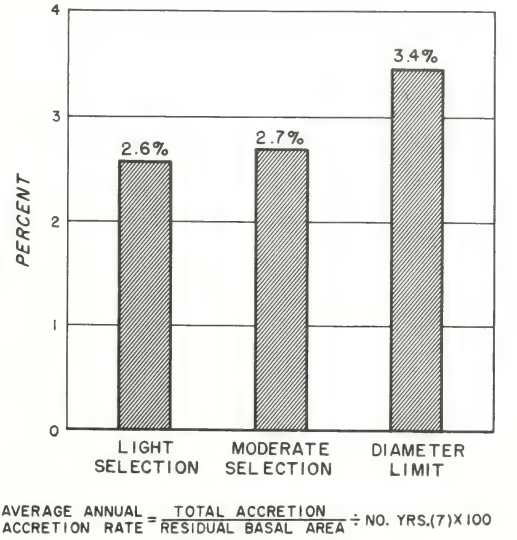


Figure 5. — Average annual accretion rates for the three partially cut plots.

Ingrowth comprises those trees that were too small to be measured in the after-logging inventory but attained measurable size during the period of observation.

Mortality comprises those trees that were alive and measured in the after-logging inventory but then died during the period of observation.

Production is accretion plus ingrowth minus mortality. It is a measure of net growth in a stand or area; it is the growth that can be harvested.

Figure 5 shows average annual accretion rates for the three partially cut plots (the liquidation plot had no significant accretion during the 7-year period). Accretion rate is the annual accretion expressed as a percentage of the residual growing stock. It is a good measure of growing-stock response to a cutting method or other treatment.

What kind of trees are accruing this growth? Quality is an important factor in managing northern hardwoods. Quality is related to tree size, as well as to form and defect; other factors being equal, larger trees produce more high-grade lumber. Figure 6 presents the plot data for accretion and production on the sawlog-size trees (all softwoods 9.5 inches and larger, and all hardwoods 10.5 inches and larger). Accretion and production

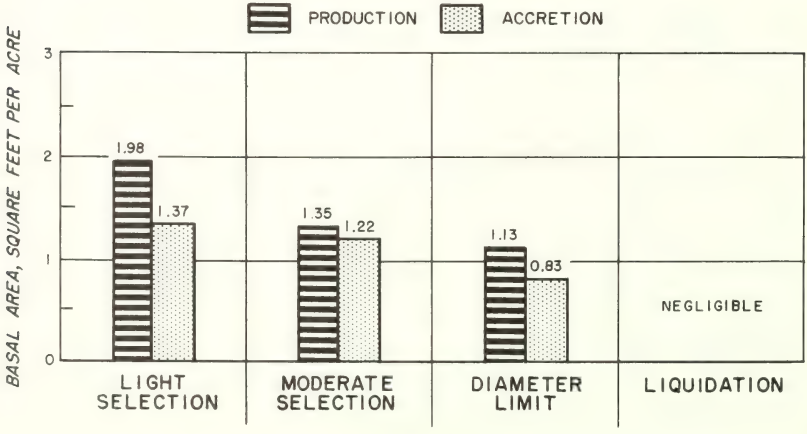
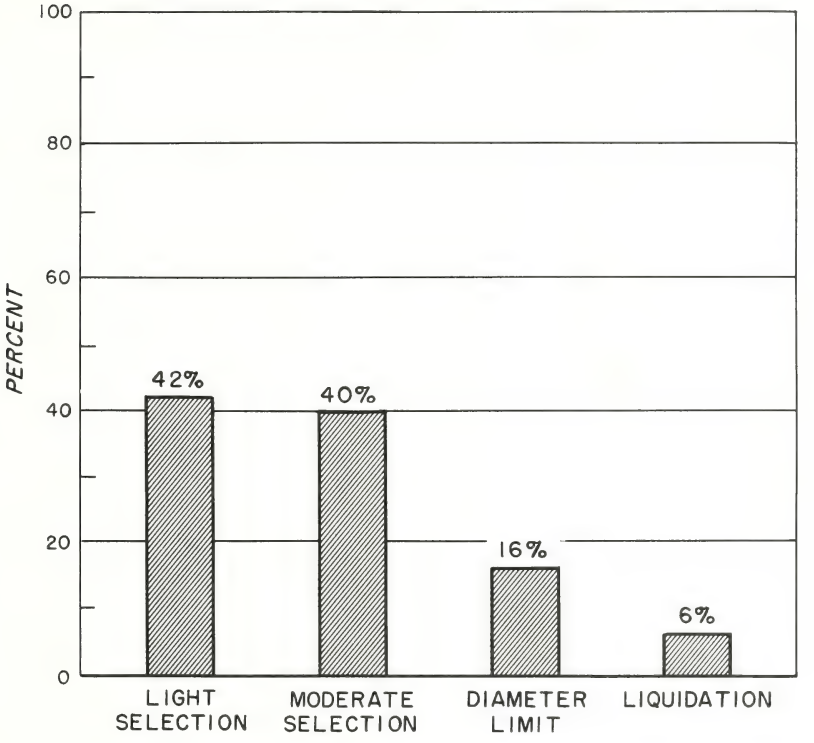


Figure 6.—Annual production and accretion on sawlog trees.

Figure 7.—Proportion of the total growing stock in trees with butt logs of grades 1, 2, or 3. Grades adapted from U. S. Forest Products Laboratory hardwood log grades. (U. S. Forest Prod. Lab. Rpt. D1737, 1953).



were greater on the selection plots where sawlog diameter classes up to 27 inches d.b.h. were represented in the growing stock.

The percentages of better quality trees (those with grade 1, 2, or 3 butt logs[4]) are shown in figure 7 for each plot as of 1959, or 7 years after the initial cutting. Both of the selection plots had a higher percentage of large, better-grade trees than the diameter-limit plot because such trees were favored when the

[4] The grades for butt logs in standing trees were adapted from: HARDWOOD LOG GRADES FOR STANDARD LUMBER: PROPOSALS AND RESULTS. U. S. Forest Prod. Lab. Rpt. D1737, 15 pp., 1953. Such log grades segregate logs into high, medium, and low groups as determined by the lumber grade yield and gross lumber yield. Thus, a grade 1 log is a high-grade log and will produce a high yield of quality lumber; grades 2 and 3 are lower on the scale, respectively, and will yield smaller proportions of high-quality lumber.

selection plots were marked for cutting; that is, the cutting was concentrated on the lower-grade trees. Also, more culls were girdled on the selection plots.

Mortality on the demonstration plots has been excessive, mainly because of heavy losses of beech and yellow birch. These two species accounted for almost 80 percent of the total. Beech losses were due largely to the beech scale-Nectria complex—an insect and disease combination. Yellow birch suffered mainly from exposure. This species is very sensitive to the environmental changes that result from logging operations.

Regeneration

Fortunately, getting adequate reproduction in old-growth northern hardwood stands under any management practice seldom is a problem. However, getting adequate numbers of desired species is another story. A regeneration survey conducted on the demonstration plots at Bartlett in 1959 bore this out. Figure 8 gives the number of milacre[5] sample plots measured in each demonstration plot and the percentages of these sample plots that were stocked with a potential crop tree.[6]

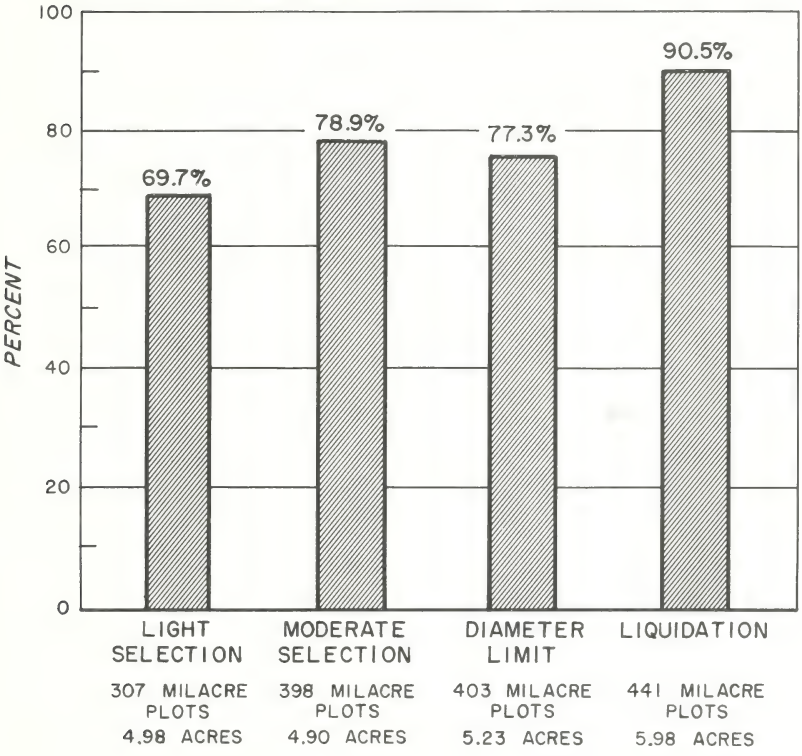
The stocking is adequate on all of the demonstration plots, including the light-selection plot where regeneration is gradual and continuous. The abundance of regeneration on the more heavily cut plots is due to improved growing conditions, particularly the increased light resulting from removal of the overstory.

Species composition of the regeneration varied considerably among plots. The lighter cuttings consistently favored the tolerant species such as sugar maple and beech. As silvuculturists often have observed, regeneration after light cuttings in northern hardwoods develops mostly from tolerant advance reproduction; that is, seedlings that already were established when the cutting was done. Light cuttings thus perpetuate the tolerant species. The heavier cuttings favored larger percentages of intermediate and

[5] Milacre = 1/1,000 acre.

[6] Potential crop tree: A tree of a commercial-species that is between 3 feet tall and 1.5 inches d.b.h. Where 2 or more trees in this size range are found on a plot, the tallest 1 is considered to be the potential crop tree.

Figure 8.—Percentage of milacre plots stocked with a potential crop tree—the tallest tree of a commercial species between 3 feet tall and 1½ inches d.b.h.



intolerant species such as red maple, yellow birch, paper birch, and white ash. These species can become established in the larger openings after cutting, and they can compete there more or less successfully with the tolerants. However, the greater the number of tolerants in the advance reproduction, the smaller will be the proportion of intolerants in the new reproduction, regardless of how heavily the stand was cut.

The crux of the reproduction problem faced by most northern hardwood timber managers when choosing a management practice is not so much the amount as it is the kind of reproduction obtained. Though advance reproduction cannot be altered, the species composition of the regeneration can be partially controlled by the degree of cutting employed.

Appraisal

The responses to stand treatments on the Management Intensity Demonstration plots 7 years after cutting are in accord with expectations derived from other experience in the northern hardwood type. In short, the plots are considered good demonstrations of the management practices they were designed to demonstrate.

However, because of the small size of the plots and the lack of replications, final judgments on the merits of the different management practices should not be based on these plot results alone. Conclusive information of this sort must and will come from the larger, long-term studies now under way.

But in the interim, cutting in the northern hardwood region will continue at its present or at an even faster rate, and forest managers urgently need at least tentative guides now on which to base their management decisions. The results from the demonstration plots, coupled with trends observed in other studies, and tempered by past experience, do give an indication of the different treatment possibilities and, if used with discretion, should provide reasonably good guidance for managing similar old-growth northern hardwood stands.

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13 Years of FORESTRY RESEARCH in West Virginia

A progress report
from the U.S. Forest Service
Timber and Watershed Laboratory

by
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13 Years of FORESTRY RESEARCH in West Virginia

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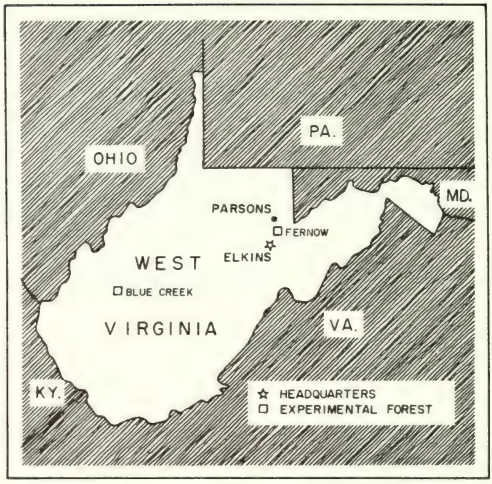

Figure 1.—Location of the forestry research facilities in West Virginia.

Figure 2.—Field offices near Parsons, West Virginia.

"...To Conduct Research"

IN 1948 the Northeastern Forest Experiment Station of the U.S. Forest Service, Department of Agriculture, established a field unit to conduct research in forest and watershed management in the Northern Appalachian Mountain region. This is a progress report on the activities and accomplishments of this research unit during its first 13 years of existence.

Known initially as the Mountain State Research Center, later as the Elkins Research Center, and since 1962 as the Timber and Watershed Laboratory, this research unit has its administrative headquarters in the U.S. Forest Service Building at Elkins, West Virginia (fig. 1). However, most of the research facilities, including the Fernow Experimental Forest, are located near the town of Parsons, 22 miles to the northeast (fig. 2). A new laboratory is now being constructed at Parsons as field headquarters for this research unit.

The Fernow Experimental Forest, a 3,640 acre tract on the Monongahela National Forest, was set aside for the use of this research unit as an outdoor laboratory for studies in managing mountainous forest land. The forest stands here are mixtures of

Figure 3.—Typical forest land in West Virginia. The research program here deals with managing forested mountain land for timber, water, and other uses.

old-growth and second-growth hardwoods dating from around 1905, when heavy cuttings were made. In topography, history of cutting, climate, and variety of species the Fernow Forest is representative of much of the timberland in West Virginia and adjacent states (fig. 3).

Though the Fernow Forest has been the main locale of the research program, other studies have been made in other parts of West Virginia, in western Maryland, and in southwestern Pennsylvania. A number of study areas are located on the Monongahela National Forest. And in 1957 an agreement was made to cooperate in forest research with the Union Carbide-Olefins Company on their land near Charleston, West Virginia. Studies are now under way there on a 2,500-acre area known as the Blue Creek Experimental Forest.

The program of research at Elkins is concerned primarily with multiple use of forest land. It stresses integrated management studies aimed toward finding practical solutions to problems of managing the timber, water, and game resources of this area. Results from these studies should provide bases for judging compatibility of uses and determining use priorities. The pages to follow present an overall view of the Elkins research program and highlight the more significant results.

The Research Program on the Fernow Experimental Forest

Research efforts here have been concentrated in the field of management, with particular attention to timber and water. Wildlife studies have been integrated with this work through cooperative agreements with other agencies.

TIMBER MANAGEMENT RESEARCH

Compartment Management

Management studies on compartments (areas ranging in size up to 100 acres) are an important part of the research program on the Fernow Forest. These compartments are treated according to different forest-management practices. In timber management, the principal objective of the studies is to compare roadside costs and returns for products harvested under different practices. In correlated watershed-management studies, the objective is to compare quantity, distribution, and quality of water yields under some of the same types of forest management.

Supplementing these studies under the multiple-use concept, deer-management technicians of the West Virginia Conservation Commission are studying the effects of different practices on production of deer browse and use of different areas by deer (fig. 4). However, the wildlife studies make up a comparatively small part of the total program on the compartments.

Figure 4.—A deer exclosure used in a study of deer browsing.

Table 1.—*Treatments on forest-management research compartments on Fernow Experimental Forest*

(Number of areas in each category)

Treatment	Site quality (oak site index)			Total
	80	70	60	
Commercial clearcut	2	2	0	4
Diameter limit	2	2	3	7
Extensive selection:				
10-year cutting cycle	3	2	2	7
20-year cutting cycle	2	2	2	6
Intensive selection:				
5-year cutting cycle	2	2	0	4
Flexible cutting cycle	3	2	2	7
Even-aged management	3	3	3	9
Check area	1	1	1	3
Total	18	16	13	47

The major factors in the timber-management compartment studies are site quality and stand treatment or management program. Site quality is the potential of land to grow timber. It is expressed as site index, which is the height of dominant and codominant trees at 50 years of age according to Schnur's oak site index curves (*19*). Site-index designations on the compartments were determined by use of a site-estimating equation. This was developed by the Elkins project (*32*) and is explained later under "Site Quality Studies."

The major treatment variables or management programs are: commercial clearcutting, diameter-limit cutting, two levels of selection management, and three levels of even-aged management (table 1 and figs. 5 to 9).

A number of guides have been set up for the management programs. For the selection compartments, the guides specify the ultimate goals in terms of distribution of trees by diameter classes, number of trees per acre, volume to be left after cutting, and the size of trees that will be grown. For the even-aged compartments, they specify the different levels of intermediate treatments to be applied.

Figure 5.—A commercial clearcutting was made here. All merchantable stems were cut, including trees as small as 5 inches in diameter at breast height. Cull trees were left. Another profitable cutting will not be possible here for 60 or 70 years. An oak site index class 80.

Figure 6.—Here cutting was limited to merchantable trees 17 inches diameter and larger. Culls of this size were killed. It is expected that another cutting can be made here in about 20 years. An oak site index class 80.

Figure 7.—Extensive selection management is being tried here. Only sawlog-size trees are considered in management. Working with the stand above 11 inches in diameter, foresters select and mark each tree to be cut. Cull trees in this size range are killed. Another cutting can be made here in about 10 years. Site index is 80.

Figure 8.—An intensive type of selection management is being tested here, and two cuttings have already been made, at 5-year intervals. To improve the stand and keep it productive, foresters select and mark each tree to be cut, including trees as small as 5 inches. Culls are killed. Site index 80. Growth rate: 500 board feet per acre per year.

Figure 9.—A seed-tree cutting was made here. About 10 vigorous seed trees per acre, of the desired species, were left. After seed from these trees has started a new stand, these trees will be cut. The new stand will be managed as an even-aged forest.

Though many of the objectives of compartment management, including the principal one relating to costs and returns, will not be attained for years, the study is already yielding valuable information on logging practices, stand improvement, growth, reproduction, and timber quality.

Logging and Skidroad Studies

When work was begun by the research unit in 1948, one of the biggest obstacles to the practice of good forest management in the area was the belief among local operators that short skidroads and very heavy per-acre cuttings were primary requisites for making money in the woods. Cultural measures were considered expensive frills. We had to demonstrate the proper use

Figure 10.—The logs being loaded here were removed from the Fernow Forest in experimental cuttings. The local cooperator will haul them to his sawmill.

Figure 11.—The Fernow Forest personnel use a crawler tractor with a two-wheel arch to winch in and skid tree-length logs.

of modern logging equipment and develop cheap and efficient skidding methods and skidroad layouts before we could arouse much interest in any but the more elementary forms of forest management. Once we had demonstrated that good forest management was compatible with reasonable logging costs, many private operators and landowners became interested in practicing forestry.

On the Fernow Forest, we do our own logging with a special crew under a cooperative agreement with a local sawmill operator. Logs are delivered to the roadside (truck road), where they are picked up by the cooperator (fig. 10). The cooperator pays the logging costs and, in addition, makes appropriate stumpage payments to the Treasury of the United States.

Recently we have been making stumpage sales of small or bulk products after the sawlog operations where such sales are compatible with research objectives. Culls, trees of undesirable species, and top and limb wood from sawlog cuttings thus are disposed of for use as such products as pulpwood, posts, rails, and charcoal

wood. In all, about 3/4 million board feet equivalent are being harvested annually, most of which is sawlog volume.

Our skidding equipment consists of a TD-9 crawler tractor and a two-wheeled arch (fig. 11). This rig is operated mostly on tractor skidroads; only rarely is it driven around through the woods. Tree-length logs are winched both up and down hill to the skidroads. The usual winching distances are within 300 feet, but if necessary we can add an extra length of cable and reach out another 100 or 200 feet.

The tree-length logs are skidded to a roadside loading deck where one man, specially trained to recognize grade, does all the bucking (fig. 12). This facilitates gathering information on quality, increases the returns from the operation, and helps to demonstrate log quality as a goal of management. The cooperator pays for the logs on the basis of grade and species.

Figure 12.—Hauled to a landing, the tree-length logs are bucked, graded, and scaled. The bucking is done by a man specially trained to cut trees into the logs that will yield the highest grades of lumber.

Figure 13.—The pattern of up-and-down-hill skidroads typical of a horse-logging operation.

Our control of the woods work has enabled us to conduct several studies on logging operations. Some of the results follow:

Logging damage during selection cutting.—Injuries severe enough to warrant removal before the next cutting were done to 3 to 5 percent of the residual trees (*28*). Felling damage was greater than skidding damage among the smaller trees (5 to 11 inches d.b.h.); the reverse was true for the larger trees.

Effect of grade on skidding costs.—With Fernow equipment, the lowest costs were recorded in downhill skidding on grades of 5 to 15 percent (*7*).

Area required for logging transport system. — In well-planned logging with a tractor and wheeled arch, about 5 percent of the forest area is required for the transport system (*10*). This breaks down to about 1.5 percent of the area in decks and truck roads and 3.5 percent in main skidroads. In contrast, a typical mountain horse-logging job seriously disturbs 10 to 15 percent of the land (fig. 13).

Directional felling.—Power-saw felling permits less directional control than crosscut-saw felling. To fell trees in the preferred direction when using a power saw, 15 to 38 percent of the trees on the Fernow require more effective means of nudging than conventional wedging. We have tried jacks for this job but found them inconveniently heavy and cumbersome for use in the woods (*23*). An efficient light-weight tool for this purpose remains to be developed.

Skidroad costs.—For logging 660 acres on the Fernow Forest, an average of 65 feet of bulldozed skidroad and 74 feet of nonbulldozed spur road were constructed per acre. This figured out to about 1 mile of skidroad (both types collectively) for 38 acres. Total cost per acre was about $4.70, of which $0.90 per acre was charged to road location and after-logging stabilization work (*26*).

Stand Improvement

The unmanaged stands on the Fernow Forest contained many cull trees—trees too defective to justify harvesting. On the average, there were 12 culls larger than 5 inches d.b.h. per acre, of which 5 trees exceeded 11 inches d.b.h. In 11-inch and larger culls gross volume averaged between 1,500 and 2,000 board feet per acre.

Selection management includes stand-improvement measures, and among these measures cull removal is rated first in priority in previously unmanaged stands. During the first or conditioning cutting in such stands, cull killing is a major operation and can best be done separately from the commercial harvest. In succeeding cuttings the cull-killing job becomes progressively smaller, and in the later cuttings in managed stands the few cull trees that are encountered can be treated most conveniently by girdling during logging operations.

Poisoning with ammate crystals applied in cups or notches chopped in the tree is the method most widely used on the Fernow Forest for cull elimination (fig. 14). However, both ax and chainsaw girdling are sometimes used, particularly when cull treatment is done as part of a logging job (*34*). Other methods that have been tried less successfully include frill applications of an amine

Figure 14. — Chopping cups in a cull tree. Chemicals placed in these cups will kill this worthless tree and thus will improve the stand.

salt formulation of 2,4,5-T and injector applications of 2,4,5-T ester (*42*).

Ammate treatment on culls acts quickly and is highly effective (*39*). In follow-up surveys, 45 percent of the treated trees on one area were found to be completely defoliated within 30 days and the others had lost, on the average, about 85 percent of their foliage. On another area, 91 percent of the treated trees definitely were dead after 3 years (table 2), and crown kill exceeded 95 percent on the few trees still showing life.

Table 2.—*Kills of ammate-treated culls on three areas after different intervals of time*

Area	Date of treatment	Date of observation	Elapsed time	Trees examined	Average d.b.h. of observed trees	Average d.b.h. of dead trees	Trees killed
			Months	*No.*	*Inches*	*Inches*	*Percent*
A	5/60	6/60	1	244	13.7	10.8	45
B	8/58	6/60	22	235	16.4	14.6	66
C	5/57	6/60	37	238	14.9	14.5	91

In the ammate tests, 6 to 15 culls per acre were treated at costs ranging from $1.32 to $3.61 per acre. These costs were based on labor at $1.20 an hour and ammate at 24½c a pound. Tree marking and supervisory costs were not included. Costs varied not only with size of culls and number per acre but also with competence of labor, accessibility of area, and roughness of terrain.

On the average, our crews treated 108 tree-diameter-inches per man-hour, and treated 44 diameter-inches per pound of ammate. Total tree-diameter-inches at breast height is a convenient measure of amount of timber treated, and it correlates well with costs per unit area. Average cost per diameter-inch was $0.017.

Other stand-improvement measures include weeding, thinning, and pruning. Work in weeding and hardwood pruning has only recently been started on the Fernow Forest; we have not yet done any thinning of young stands. In places, grape vines and rhododendron are our most troublesome weed species. Methods for controlling these plants are being studied on a small scale.

Growth

One of the most important criteria used in evaluating any system of forest management is the growth rate associated with it. Rate of timber growth is the basis of any management plan or any cutting budget. Two aspects of growth are being studied: stand growth and individual tree growth.

Stand growth.—Periodic 100-percent inventories are used in studying stand growth. Growth is studied in relation to the forest-management system, site capability, and stocking. It is expressed for the total stand over 5.0 inches d.b.h., or for various components of it, in the following volume units: cubic feet, board feet of sawtimber, board feet in different log-grade classes, and basal area.

Growth is under study on the compartments, on 5-acre management-intensity plots (*8, 25*), on woodlots (*11*), and on twelve 2½ acre growing-stock-level plots (figs. 15 and 16). The longest measuring period to date is 10 years, and measurements over a range of sites and degrees of stocking have been made for only 6 years. Although the measuring periods have been too short to permit firm comparisons of growth between management systems,

Figure 15.—Growth studies indicate that this stand, on an excellent site, contains about 20,000 board feet per acre in trees larger than 11 inches d.b.h.

Figure 16.—This stand, on a fair site, contains about 4,000 board feet per acre in trees 11 inches and larger. Growth studies demonstrate the importance of site.

the short-term data indicate that the ranges of board-foot growth rates under selection management for three site-capability classes (site indexes for oak) are about as follows:

Site index	*Annual board-foot growth per acre*[1]
80 (75-84) — excellent	400 to 600
70 (65-74) — good	250 to 400
60 (55-64) — fair	100 to 250

Tree growth.—Individual tree growth has been studied not only on the Fernow Forest but throughout West Virginia. Two survey-type studies have been made and reported.

One study dealt with diameter growth in relation to tree-vigor class and to tree diameter of yellow-poplar (*6*). Using vigor classes I, II, III, and IV—based largely on crown position and size, in descending order of vigor—10-year diameter growth was found to be significantly related to vigor class:

Vigor class	*Average diameter growth (inches)*
I	3.29
II	2.56
III	1.76
IV	1.07

The data were taken in well-stocked, even-aged yellow-poplar stands on good to excellent sites. Growth was significantly related to tree size only among trees in vigor class I.

The second study dealt with diameter growth of five upland oaks in relation to the same vigor classes, to d.b.h. class, and also to site index (*38, 24*). Significant growth differences were found among vigor classes and site-index classes (fig. 17). In only one species, red oak, and only among Vigor-I trees was growth significantly related to d.b.h. class. These data, too, were collected in well-stocked, even-aged stands.

We have started an individual-tree study to learn more in detail about the factors affecting growth in diameter, in total height, and in merchantable height. Periodic measurements are being taken

[1]Based on International 1/4-inch kerf rule, for trees over 11 inches d.b.h. to an 8-inch top diameter inside bark.

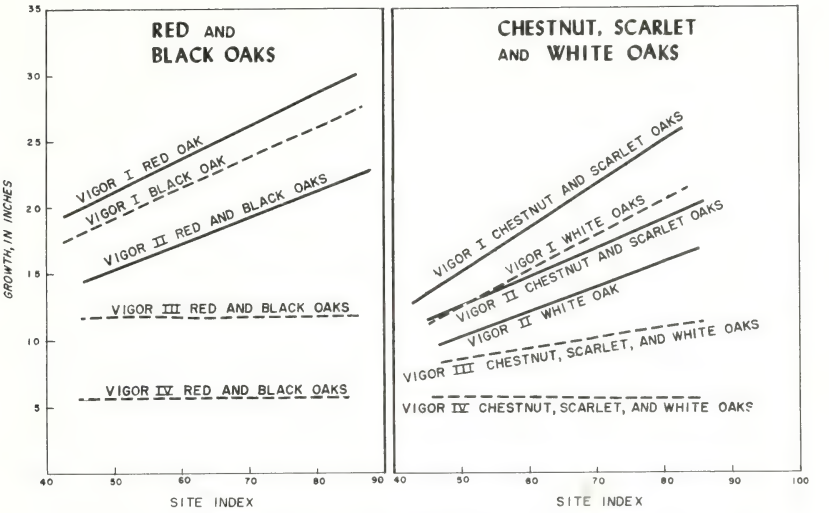
RED AND BLACK OAKS
CHESTNUT, SCARLET AND WHITE OAKS
GROWTH, IN INCHES
VIGOR I RED OAK
VIGOR I BLACK OAK
VIGOR II RED AND BLACK OAKS
VIGOR III RED AND BLACK OAKS
VIGOR IV RED AND BLACK OAKS
VIGOR I CHESTNUT AND SCARLET OAKS
VIGOR I WHITE OAKS
VIGOR II CHESTNUT AND SCARLET OAKS
VIGOR II WHITE OAK
VIGOR III CHESTNUT, SCARLET, AND WHITE OAKS
VIGOR IV CHESTNUT, SCARLET, AND WHITE OAKS
SITE INDEX
SITE INDEX

Figure 17.—Regressions and growth relations to site index. Curves show 10-year d.b.h. growth (in inches, inside bark) over site index. Solid lines represent regressions, dashed lines either percentage relationships or averages.

on about 1,200 trees to define how tree size, stand density, crown characteristics, and site quality affect growth. We plan eventually to study all of the major species in the northern Appalachian area.

Hardwood Log Quality

Improvement in log quality, which translates into improved lumber quality,[2] is a basic requirement for profitable hardwood forest management. The spread in stumpage value among logs of different grades is very wide. For the better lumber species on the Fernow Forest, the relative stumpage values of log-grades 1, 2, and 3 stand in an approximate ratio of 1 : 0.5 : 0.09 respectively. Lower-grade sawlogs often are operated at a loss.

The following steps to improve grade in forest stands should be part of every hardwood management program:

- Eliminate culls.

[2]The yardstick to quality used here was the Forest Products Laboratory standards as published in HARDWOOD LOG GRADES FOR STANDARD LUMBER. PROPOSALS AND RESULTS. U. S. Forest Prod. Lab. Rpt. D1737, 15 pp., 1949.

- Grow large trees (large sawlogs produce more grade lumber).
- As periodic cuttings are made, mark to develop a well-stocked stand of straight, clean-boled trees of desirable lumber species.

Selectively managed areas on the Fernow Forest demonstrate the effectiveness of management in improving log quality in a 10-year period. Some results from our management-intensity plots and our small woodlots are given below. All stands were on good to excellent sites (site index 70-80 for oak).

On management-intensity plots.—On two 5-acre plots, selectively cut first in 1949 and again in 1959, good management in the brief span of 10 years has resulted in a marked improvement in stand quality. Culls have been eliminated, and the proportion of the volume in grades 1 and 2 has been substantially increased, as shown in the tabulation below (averages, in board feet, for both plots):

	Total per acre	*In log grades 1 & 2*	*In log grades 3, 4 & 5*	*In cull trees*
Before first cut (1949)	14,152	3,790	9,718	1,245
After second cut (1959)	9,553	3,916	5,636	0

On small woodlots.—Estimates of log grades (based on sampling grades in standing trees) were made on two 30-acre woodlots intensively managed over a 10-year period. Annual harvest cuttings were made in each. Here too, the proportion of the volume in grades 1 and 2 has been substantially increased. The tabulation below, in board feet, shows the changes in timber quality separately for each area:

Area 1	*Total per acre*	*In log grades 1 & 2*	*In log grades 3, 4, 5 & 6*[3]	*In cull trees*
Before first cut (1949)	5,357	876	3,735	746
After last cut (1959)	4,978	1,318	3,564	96
Area 2				
Before first cut (1949)	10,580	2,768	6,459	1,353
After last cut (1959)	9,685	4,465	5,036	184

[3]Class 6 represents cull material in merchantable trees.

Reproduction

Only recently have intensive hardwood reproduction studies been undertaken by the Elkins project. However, periodic reproduction surveys have been made on all Fernow compartments and in connection with many plot studies (27). In addition, reproduction observations were made in well-stocked stands across a range of sites in West Virginia and in western Maryland during an oak site-index study.

The surveys on the Fernow compartments and plots showed that almost any kind of cutting in sawtimber stands will result in abundant reproduction of commercial species. They show also that the quality of the site and the severity of the cutting affect the amount, growth, distribution, and species composition of the reproduction.

These surveys reflect only the short-term effects (10 years at the longest); not until the present seedlings and saplings have reached pole-timber size will a clear picture of the relationships between cutting method and stand regeneration be obtained. Moreover, the nature and timing of cultural treatments, if any, and subsequent cuttings will modify the effects of original cuts.

In summation of the reproduction survey data, it can be said that:

- Reproduction is easy to establish; later development remains to be determined.
- Light selection cutting tends to result in reproduction composed largely of tolerant species unless a group-selection method is followed (figs. 18 and 19).
- Heavier cuttings predispose to higher proportions of sprout growth. Studies on the Fernow indicate that commercial clear-cuttings probably will produce stands composed of 35 percent or more sprouts; light selection cutting probably will result in stands containing less than 10 percent sprout stems.
- Differences in site quality are reflected in differences in species composition of the reproduction. For example, yellow-poplar reproduction is abundant on heavily cut areas on excellent sites

Figure 18.—A light selection cutting, showing reproduction of tolerant sugar maple.

Figure 19.—A group selection cutting, showing good reproduction of yellow-poplar in an opening.

but rare on heavily cut fair sites. Oak reproduction, almost absent on excellent sites (even with oak seed trees present in the overstory), is represented consistently but sparingly on the good sites, and is moderately plentiful on the fair sites.

- In our observations, sugar maple was the most prolific species on all sites and following all degrees of cutting, with these exceptions:
  1. On excellent sites following clearcuttings, where yellow-poplar was more numerous.
  2. On very lightly cut areas on good and fair sites at lower elevations, where beech and sassafras were more abundant.
- On partially cut areas, reproduction of intolerants was relatively much more abundant in openings than under canopy.

The oak site-index study sampled fully stocked stands in which oak species made up 30 percent or more of the overstory (38). Natural oak reproduction, like the distribution of oak trees, was more prevalent on the medium to poor sites (table 3).

Indications are that oaks may maintain themselves pretty well on areas with a site index 65 or lower. On better sites, competition from faster growing or more tolerant species appears to make conditions less conducive to the establishment of oaks.

There is a definite correlation between the prevalence of the different oak species and site quality (table 4). Northern red oak

Table 3.—*Natural reproduction under oak stands, by site index*

Site index	Plots	Trees per acre, all species	Oak reproduction			Trees 5.0 inches d.b.h. and over that are oaks
			Per acre	Percent of all species	Relative frequency	
	No.	*No.*	*No.*	*Percent*		*Percent*
40	4	3,600	1,700	47	1st	82
50	5	4,800	1,480	30	1st	82
60	17	4,200	1,100	26	1st	62
70	24	3,000	400	14	3rd	47
80	15	3,000	80	3	9th	32

Table 4.—*Distribution of oak reproduction, by species and site index*

Site index	No. of plots	Number of trees				
		Red oak	Chestnut oak	White oak	Scarlet oak	Total per acre
40	4	0	1,100	300	300	1,700
50	5	400	440	560	80	1,480
60	17	520	400	60	130	1,100
70	24	58	308	34	0	400
80	15	54	0	26	0	80

is absent on the areas of lowest site index and scarlet oak is absent from the better sites.

In 1960 a reproduction study was started on the even-aged management compartments. It included areas of oak site indexes 60, 70, and 80. Seed trees were left following the first reproduction cut; they will be harvested 3 years later. Objectives of the study are:

- To observe species composition, quantity and quality of reproduction, growth rates, and occurrence of sprouting.
- To test locally the hypothesis that this type of cutting will permit or encourage reproduction of certain desirable tree species (most of them intolerant).
- To measure and evaluate sprout growth by species, stump diameter, and tree-age classes.

Management Unit

The objective in this project is to manage by simple, practical methods a 600-acre tract of hardwoods, with emphasis on obtaining a maximum continuous return. The study will be a step toward translating research results into guides for better management plans for medium-sized forest holdings. It is a research project in economics, with considerable demonstration value.

The management unit is comparable to a private forest operated under current local conditions of markets, labor supply, transportation, and other economic factors.

Some limitations and imperatives are involved in the study: First, the woods must be cut under a sustained-yield schedule to provide material for our cooperator's mill. Second, the operation must pay all costs, including the appropriate forest-management costs, and yield a fair stumpage return. The type of forest management applied, including cultural measures, will be the best possible within the limitations. Simplified records are being kept for the purpose of calculating net returns. An important objective of the study is to evaluate such forestry costs as marking and management inventory.

The cutting program is under way. The first operations follow marking on a selection basis; a system of all-aged silviculture is envisioned. Approximately a 20-year period will elapse before the second cutting.

Small Forest Properties

In 1948, intensive selection management was started on two 31-acre demonstration woodlots. The purpose was to show that the owner of a small woodlot could obtain some income from it each year while at the same time he could build up stand quality and value for increasingly higher returns. Annual cuttings have been made in each woodlot, and results for the first decade of management have been analyzed (*11*). The analysis covers both silvicultural and economic aspects.

Each stand is on a good site. Both areas had been cut for sawlogs about 40 years before the study was begun. Area 1, being nearer an old logging railroad, had been cut more heavily; it also had been burned more severely. Consequently, the initial stand capital in 1948 was much less here than in Area 2. Table 5 shows stand data for the two areas in the beginning and after 10 years of management.

Returns from management of the woodlot areas have been realized in two forms: (1) monetary returns from the annual cuttings, and (2) increased value of the stands.

The cuttings during the 10-year period have yielded approximately 2,000 board feet per acre on Area 1 and 3,750 board feet per acre on Area 2. The increase in stand value came about

Table 5.—*Changes occurring during 10 years of management on small woodlots*

Date	Merchantable volume per acre	Percent of merchantable volume		Basal area in culls	Annual per acre growth for the period[1]
		In high-value species	In log grades 1 and 2		
	Bd.ft.	*Percent*	*Percent*	*Percent*	*Bd.ft.*
Area 1:					
1949	4,600	56	19	6.5	—
1959	4,880	76	27	1.7	230
Area 2:					
1949	9,200	69	30	10.0	—
1959	9,500	76	47	1.8	400

[1]Includes material removed as well as changes in stand volumes.

in these ways: (1) through a small increase in merchantable volume; (2) through a change in species composition, with increased volume in high-value species; and (3) through an improvement in log grade or quality.

We have set up management goals for each woodlot area in terms of merchantable volume and timber quality. We believe these goals to be realistic and attainable approximately as scheduled below:

Year	*Merchantable volume/acre (bd. ft.)*	*Sawlog volume in high-value species (percent)*	*Sawlog volume in log grades 1 & 2 (percent)*
Area 1:			
1959	4,880	76	27
1969	6,400	80	40
1979	8,100	80	50
1989	10,000	80	60
Area 2:			
1959	9,500	76	47
1969	10,000	80	60

WATERSHED-MANAGEMENT RESEARCH

The watershed-management-research program, from its inception in 1950 to the present, has grown in importance and complexity. Since watershed management is one of the main elements in multiple-use management of forest land, many aspects of watershed-management research impinge on timber-management practices, and vice versa. From the beginning, we have viewed watershed management and timber management as interrelated and complementary facets of forest-land management. In our watershed studies we have always tried to recognize the timber-management implications, and have tried to integrate our research in the two fields.

The broad objective of the watershed-management-research program is to determine the effects of land-use changes and forest practices on the quality and quantity of streamflow, and its distribution in time. Recommendations and prescriptions are coming from this research. The research program can be divided into two parts: studies of gaged watersheds, and other studies. Most of the research effort has gone into the gaged watersheds.

Gaged Watersheds

Because reports recently published (*16, 18*) treat in detail the work on gaged watersheds, only the highlights will be covered here.

In the spring of 1951 observations and records were started on five gaged watersheds on the Fernow Experimental Forest. Research installations included stream-gaging stations with V-notch weirs, water-level recorders, a weather station, and a rain gage network of three recording and nine standard gages (figs. 20 and 21). The forest areas behind the stream gages range from 38 to 96 acres. In 1951, all were undisturbed and supported well-stocked stands of hardwood timber. The five watersheds are nearly contiguous and are reasonably similar in forest types, soils, and topography (table 6).

Figure 20.—A weir and gage house of the type used in watershed-management studies. This is a view from upstream.

Records on precipitation, runoff, and water quality were gathered on the undisturbed watersheds over a 6-year calibration period. This established the patterns of natural behavior, which then served as a yardstick for judging the effects of subsequent watershed treatments on runoff and water quality. To provide a reliable yardstick, the requisite length of calibration period was determined by interim statistical analyses of streamflow and precipitation data compiled by months, seasons, and years (*13*).

Also, inventories of the timber were made during the calibration period. Since the watersheds were destined, after treatment, to function as replicates in the timber-management compartment study, the inventories served two purposes: to provide a base for planning and specifying cutting treatments, and to provide a base for relating stream behavior to forest cover.

Figure 21.—Instrument installations used in watershed studies. Right foreground, a standard rain gage. Middle distance, left, a recording rain gage. Background, a weather-instrument shelter.

Four of the watersheds were treated between May 1957 and February 1959; the fifth was left undisturbed as a control. The treated areas were cut over according to different systems. These ranged from a commercial clearcutting, with skidroads located by the loggers up to maximum operable grades, to a conservative selection system of cutting, with carefully laid out and drained skidroads restricted to low grades (table 6).

Effects of the treatments in terms of water quality and stream flow are discussed below for the 3-year period from the start of treatment through April 1960; some data also are given for the 1960 growing season.

Water quality.—Water turbidities after treatment illustrate the striking results of the different logging practices. (Turbidity is expressed in parts of soil per million parts of water—ppm.) The water turbidity ranged from 15 ppm. on the control to 56,000 ppm. on the clearcut watershed.

Serious stream pollution occurred on the clearcut watershed and on one cut to a diameter limit. These were the heavier cuttings in the study, and skidroad locations were unplanned and unrestricted. On the other two watersheds, where road layouts were

Table 6.—*Characteristics of five gaged watersheds on the Fernow Experimental Forest*[1]

Watershed No.	Timber management practice	Area	Basal area in trees over 5.0 inches d.b.h.		Range in elevation	Skidroad area steeper than—	
			Original	Removed		10%	20%
		Acres	*Sq. ft./acre*		*Feet*	*Percent*	
1	Commercial clearcut	74	98.2	81.0	2,040-2,610	78	46
2	Diameter limit	38	95.0	34.3	2,350-2,620	80	8
5	Extensive selection	90	111.4	24.0	2,400-2,760	64	7
3	Intensive selection	85	104.6	14.8	2,400-2,810	32	1
4	Control	96	105.7	0	2,400-2,820	0	0

Soils are medium texture on all areas, mostly well-drained silt loams.

planned according to grade specifications and the cutting was selective, pollution was much less. On one of these watersheds, cut according to extensive selection standards, the effect on water quality was not serious and subsided soon after logging; on the other, cut according to intensive selection standards, the effect on water quality was negligible.

The impact of logging on water quality was greatest while the logging was in progress. This is shown below by some averages of periodic turbidity measurements made during and after logging the clearcut and diameter-limit watersheds:

	Average turbidity (ppm.)	*Range in turbidity*
Commercial clearcut:		
During logging	490	0-5000
First year after logging	38	0-700
Second year after logging	1	0-53
Diameter-limit:		
During logging	897	0-5000
First year after logging	6	0-88
Second year after logging	0	0

Heavy cutting widened the extremes of water temperatures. On the average, growing-season maximums in 1958 and 1959 were increased on the clearcut area by about 8° F., and dormant season

minimums were reduced about 3½ . Slight effects of the same sort were observed on the diameter-limit watershed. But no appreciable effects were evident on the two selection watersheds.

Slight chemical changes in the water were also noted as a result of clear cutting: pH increased by about 0.3 and methyl orange alkalinity rose about 2 ppm. No appreciable changes occurred after the other three treatments.

Streamflow.—Treatment effects were analyzed in terms of: total discharge by years, seasons, and months; low flows; high flows; flow duration; and runoff as a percentage of precipitation. By using equations determined during the calibration period,

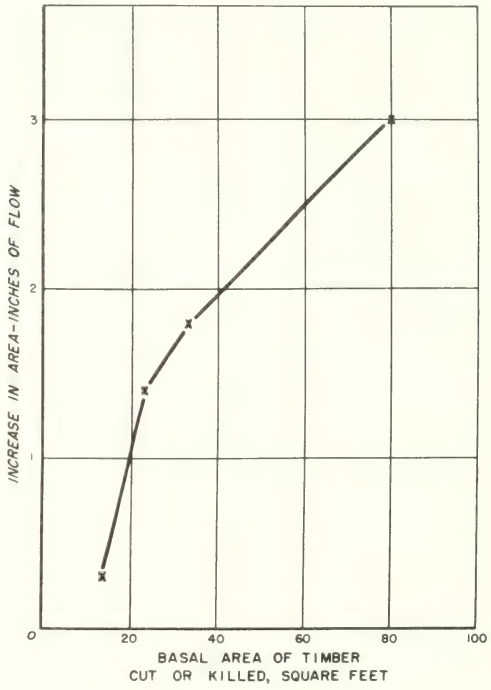

Figure 22.—Relationship between amount of timber cut or killed and increase in stream discharge, 1959 growing season.

after-treatment flow could be compared to the flow that would have occurred under comparable rainfall and weather regimens in the undisturbed stands. The treatments increased total discharge, more or less in proportion to the amount of timber cut (fig. 22). Most of the increase occurred in the summer and early fall.

Table 7.—*Effect of watershed treatment on discharge, by seasons*

Year	Increase in flow[1]							
	Commercial clearcut		Diameter limit		Extensive selection		Intensive selection	
	Area-inches	*Per-cent*	*Area-inches*	*Per-cent*	*Area-inches*	*Per-cent*	*Area-inches*	*Per-cent*
Growing season								
1958	4.4*	34	—	—	—	—	—	—
1959	3.0*	111	1.8*	53	1.4*	33	0.3	9
1960	1.8*	35	.7*	11	[2]–.3	4	.4	7
Dormant season								
1957-58	0.9	5	—	—	—	—	—	—
1958-59	.6	4	.2	1	–.1	1	3	2
1959-60	.5	3	.8	4	–.6	2	0	0

[1]Increase is expressed as a percentage of expected discharge.
[2]Negative value denotes a decrease.
*Increase is statistically significant at 5-percent level.

Predicted flows—if no cutting had been done—and measured flows, after different methods of cutting, were compared for growing and dormant seasons (table 7). On all treated watersheds except the one cut by intensive selection, significant increases in total discharge occurred in the first growing season after logging

was completed. The largest increase, as would be expected, occurred on the clearcut watershed; and the smallest increase was where the cutting was lightest—on the intensive selection watershed. Although not statistically significant, the increase on the intensive-selection watershed was estimated to be 0.3 area-inch, or more than 8,000 gallons per acre; and it fell into a logical pattern in relation to results on the other watersheds. Even in the short period of observation, the streamflow records indicate that the increases in runoff due to cutting treatments are diminishing.

Dormant-season increases, ranging up to 5 percent on the clearcut watershed, were not statistically significant.

Effects of the treatments in augmenting low flow were particularly striking. For each treated watershed, equations were derived for predicting the number of days in the year that its flow would have fallen below 0.05 (about 50 gallons per acre per day) if no cutting had been done. Table 8 shows the expected days of low flow under no treatment and the actual days of measured low flow under the treatments. Fewer days in the measured column indicates that the treatment resulted in an increase in flow.

Table 8.—*Effect of treatment on number of days of low flow (below 0.05 csm)*

Treatment	Year	Number of days of low flow		
		Expected	Measured	Decrease
Commercial clearcut	1957	124	52	72*
	1958	38	0	38*
	1959	99	36	63*
	1960	46	7	39*
Diameter limit	1958	22	0	22*
	1959	74	27	47*
	1960	29	2	27*
Extensive selection	1959	58	37	21*
	1960	17	3	14*
Intensive selection	1959	65	60	5
	1960	20	7	13*

*Decrease is statistically significant at 5-percent level.

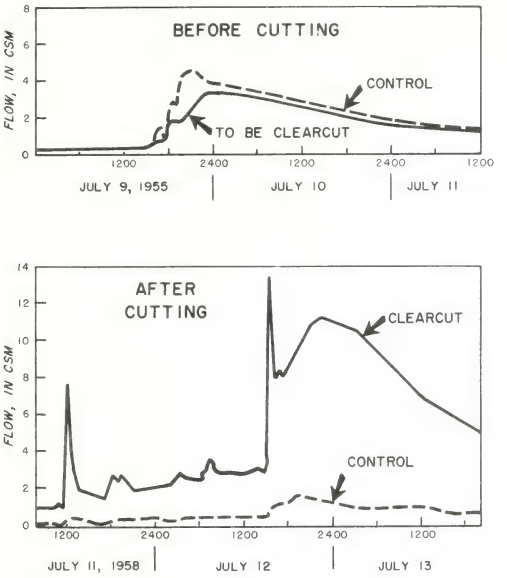

Figure 23. — Sample storm hydrographs of clearcut and control watersheds before and after treatment.

There was a definite effect of treatment on high flow, at least on the clearcut watershed. This effect was much more difficult to analyze than the effects on other aspects of streamflow. The high-flow responses after treatment were not consistent for different storms. The variations appear to be associated with time of year, antecedent precipitation and soil-moisture conditions, presence or absence of snow, and other factors. Too few high flows occurred to permit stratification by these factors.

Under some conditions, storm flow from the clearcut watershed was several times that from the control. Figure 23 shows sample hydrographs for these two watersheds before and after treatment. The two pretreatment hydrographs are similar; the rounded peaks are characteristic of undisturbed forested watersheds where overland flow is negligible.

In an effort to define the effects of heavy cutting on storm flow, several different analyses were made. Two of these are noted below. All were in general agreement in indicating higher high flows after the treatment than before. One analysis compared predicted and measured values of instantaneous peak flows. On

the average, the absolute height of peaks during the growing seasons was increased 21 percent. In another analysis, the volume of discharge above 10 csm. was determined for the period of high flow. On the average, flow above 10 csm. during the growing season was increased 75 percent.

The treatments had little effect on high flows during the dormant season: both small decreases and small increases occurred. Effects of treatment on the rate of snow melt probably accounted for most of the dormant-season variations. Treatment effects on high flows on the other three watersheds were small as compared to those on the clearcut area.

This study of gaged treated watersheds is being continued to determine changes in streamflow resulting from regrowth of the vegetation and to learn the effects of future cuts.

Additional analyses of accumulated data may enhance our understanding of precipitation-streamflow-treatment relationships. The possibility of relating streamflow to such weather variables as temperature and humidity remains to be explored. Separation of streamflow into surface runoff, subsurface flow, and ground water should give a better understanding of the role of these three components in the overall relationships.

Other Gaging Studies

Four untreated watersheds are now being calibrated. Two are forested watersheds on the Fernow Experimental Forest where additional studies of cutting effects will be made in a few years. Two others are brushy mountain pastures off the forest that now are reverting naturally to woodland. On these areas methods of conversion to forest will be studied in relation to streamflow and water quality.

Other Watershed-Management Research

Besides the gaging studies, our most notable watershed research has concerned practices and after-logging treatments to control erosion on logging roads. This work was started early in the Fernow program. Several other small miscellaneous studies will be mentioned briefly.

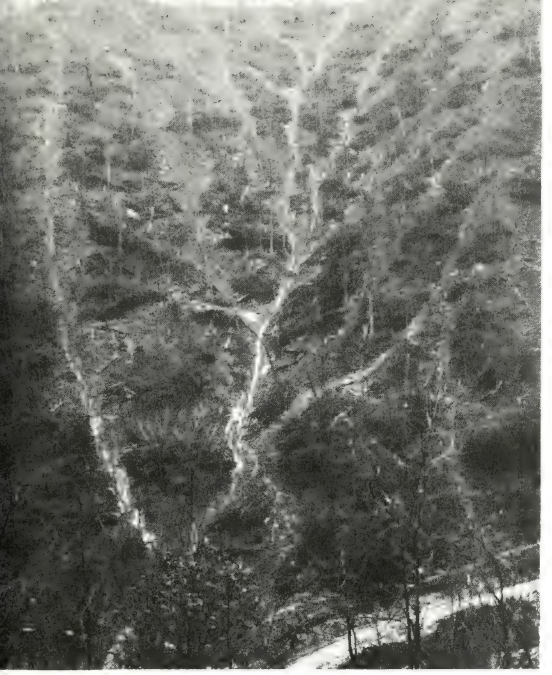

Figure 24.— These skid-roads, running straight up and down the hill, wash and gully with every rain.

Control of logging-road erosion—Logging-road erosion was studied in relation to steepness of slope, provision for drainage, intensity of use, soil factors, and revegetation measures. Results of these studies have been reported in a number of publications (*33, 35, 29, 36, 31. 21, 22*). The study findings have led to the following recommendations for the general northern Appalachian area:

- Disturb as little soil as possible; plan and construct a minimum mileage of roads.
- Keep grades of bulldozed roads under 10 percent, if possible (fig. 24 illustrates what not to do in road location).
- Locate roads on side slopes so they can be adequately drained.
- Bulldoze only where necessary and only for permanent roads. Subsoil is more susceptible to erosion and it stabilizes more slowly than topsoil.
- When bulldozing a road, make frequent dips and breaks in grade.
- Log and get out. Logging should be concentrated in one sec-

Table 9.—*Soil loss from skidroads, by intensity of use, in inches*

Road	During skidding	First two months after skidding	Total after-logging erosion[1]
Heavily used			
No. 1	5.4	0.4	[2]1.8
No. 2	2.0	1.1	2.1
Lightly used			
No. 1	.8	.1	[2].8
No. 2	1.3	.3	1.0
No. 3	.8	.1	.7

[1]This covers the period until the road surface was considered to be stabilized.
[2]Water bars were installed after logging on both No. 1 roads but not on the other roads.

tion of a logging chance at a time so that the skidding period can be reduced to a minimum. Erosion is greatest during the period of use (table 9).

- Keep road-building and skidding away from stream courses. Divert water from skidroads onto the forest floor where the sediment can be filtered out, rather than directly into streams.
- When skidding on a road is finished, install water bars or outslope drainage at appropriate intervals determined by the grade. A workable rule of thumb for determining the spacing in feet between drainage points is to divide the slope percent of the road into 1,000.
- On areas of high erosion hazard, apply lime and fertilizer after drainage has been installed, and seed coarse meadow or cereal grasses for additional erosion control (fig. 25).

Miscellaneous Studies

Ground rainfall intensity.—Rainfall intensities and throughfall were measured under a fully stocked hardwood forest over a period of 1 year. (Throughfall is the rain that falls through the tree crowns; the amount that runs down the tree trunks—stemflow—is excluded). Maximum 5- and 15-minute intensities were compared with similar measurements in the open. The results

Figure 25.—Log decks can be a source of erosion. *A*, this log deck was seeded to produce new cover. *B*, this log deck was not seeded. Both photos were taken 1½ years after logging.

Figure 26.—A small filter dam, used to trap sediment. The dam was made of a crosslog, posts, stock wire, and straw.

were analyzed separately for bare-canopy winter and for full-leaf summer conditions. Regression equations were calculated for estimating intensities and throughfall under canopy from measured rainfall in the open. In the study, low rainfall intensities were reduced more by summer canopy, and high intensities were reduced more by winter canopy. Throughfall was reduced about the same amount in both summer and winter (*30*).

Streamfilter.—A small filter dam was developed to catch stream sediment from an area that was being logged without regard for watershed damage. Several of these dams on the stream prevented much of the sediment from moving into a municipal reservoir below (*14*) (fig. 26).

Humus studies.—On several watersheds periodic observations are being made to determine the effects of different intensities of cutting on type and depth of humus. Humus depth 3 years after the commercial clearcutting showed a significant reduction of 1/3 inch in the A_1 horizon.

Automatic water sampler and trash screen lifter.—The Elkins and Laconia (New Hampshire) projects jointly developed a "Rube Goldberg" type of automatic apparatus for collecting water samples and raising trash screens when streamflow reaches predetermined stages (*17*). The apparatus is operated by tripping devices activated by rising water in the weir pond.

Soil-moisture study.—Some soil-moisture investigative work has been done on the watersheds both by conventional gravimetric sampling and with one of the earlier types of neutron moisture probes. This work, while inconclusive, did lead to the development of certain hypotheses concerning soil moisture in this area. These may form the bases of future soil-moisture research.

Also in connection with our soil-moisture work, a method was developed to adjust moisture content for stone volume (*15*). In gravimetric sampling, moisture-content estimates can be improved by removing stones from the samples and deducting the weight of stones from total soil weight and the weight of moisture in stones from weight of moisture in the sample. Adjustments must also be made when determining soil bulk density if moisture content by volume is desired, and in applying soil-moisture values to soil areas that include stone.

The Research Program On Other Areas

SITE-QUALITY STUDIES

Soon after establishment of the Elkins projects, we became aware that forest land site quality (the potential of land to grow timber) in this area varies greatly, even over short distances. Variations in site, accompanied as they are by differences in species composition and growth rates, obviously would have to be considered, both in studies of treatment effects and in the development of forest management and silvicultural prescriptions.

The most readily available and best recognized measures of site quality were the standard site indexes—the heights of dominant and codominant trees at 50 years of age. But site index can be determined accurately only from trees growing in undisturbed, reasonably well-stocked, even-aged stands. Many—probably most—of our forest stands fail to meet these conditions. Therefore

other methods of determining forest land productivity were needed.

In 1953 work was begun to find ways of determining site index, from the site itself, for the principal timber species in this general area. We started with the oaks because they comprise at least half of the timber resource in the area, and because good site curves and yield-table[4] data were available (*19*).

From this work an estimating equation was developed by regression analysis for well-drained, medium-textured soils originating from sandstone and shale, except the Ashby series. The equation applies to the Allegheny Plateau and Allegheny Mountain regions of northeastern West Virginia and western Maryland (*32, 37*). We found the following four variables to have a major influence on site index of a given plot of land: (1) aspect or compass direction faced by the slope of the land; (2) its position on the slope—that is, its distance from the ridge line in percentage of total length of the slope; (3) its grade or percentage of slope; and (4) soil depth to rock.

In the regression equation, site index (Y) is expressed as its logarithm to the base 10. The four independent variables named above were made linear with respect to site index by expressing them as follows:

1. Aspect (X_1) as the sine of the azimuth taken clockwise from the southeast and adding 1.
2. Slope position (X_2) as the percentage of distance from the ridge line.
3. Grade (X_3) as the percent slope.
4. Soil depth to bedrock (X_4) as its reciprocal in feet. Or, more concisely, the elements in the equation were defined as shown below:

$$Y = \text{log site index}$$
$$X_1 = \text{sine (azimuth from SE)} + 1$$
$$X_2 = \text{percent distance from the ridgeline}$$
$$X_3 = \text{percent slope}$$
$$X_4 = \frac{1}{\text{soil depth in feet}}$$

[4]Yield tables, based on actual measurements in well-stocked stands, indicate the approximate timber yields that can be expected from different sites.

The equation developed from the study is: $Y = 1.9702 - 0.0618\ X_1 + 0.0012\ X_2 - 0.0020\ X_3 - 0.1509\ X_4$. The correlation coefficient of 0.8683 is significant at the 1-percent level. The standard error of estimate is approximately 9 percent at the point of average site index—66 feet. The effect of these factors can best be seen when expressed in tabular form (table 10).

Factors other than those used in the equation, such as soil texture, drainage, and stoniness, also modify site quality. The effects of these variables are discussed in the technical report of this work (*32*).

Table 10.—*Site index of oak as related to aspect, slope position, slope percent, and soil depth*

Aspect	Soil depth in feet	Slope percent							
		10	30	50	70	10	30	50	70
		TOP OF SLOPE				UPPER SLOPE			
SW (225°)	0.5	34	31	28	26	37	33	31	28
	1.0	46	43	40	36	52	47	43	39
	2.0	57	52	47	43	62	56	51	47
	3.0	60	55	50	45	65	60	54	50
NW (315°) and SE (135°)	0.5	39	35	32	29	42	39	35	32
	1.0	55	50	46	42	60	55	50	45
	2.0	65	59	54	49	71	65	59	54
	3.0	69	63	57	52	75	69	63	57
NE (45°)	0.5	45	41	37	34	49	44	41	37
	1.0	63	58	53	48	69	63	57	52
	2.0	75	69	63	57	82	74	68	62
	3.0	80	73	66	60	87	79	72	66
		LOWER SLOPE				BOTTOM OF SLOPE			
SW (225°)	0.5	40	37	33	30	44	40	37	33
	1.0	57	52	47	43	62	57	52	47
	2.0	68	62	56	51	74	68	62	56
	3.0	72	65	59	54	78	72	65	60
NW (315°) and SE (135°)	0.5	46	42	39	35	50	46	42	38
	1.0	66	60	55	50	72	66	60	54
	2.0	78	71	65	59	85	78	71	65
	3.0	83	75	69	63	91	83	75	69
NE (45°)	0.5	53	49	44	41	58	53	49	44
	1.0	76	69	63	57	83	76	69	63
	2.0	90	82	75	68	99	90	82	75
	3.0	95	87	79	72	104	95	87	79

After the results of this study had been published, further analysis—strengthened by the addition of more data—showed that site index could be estimated without the measurement of soil depth. Otherwise, the same factors were used; that is, X_1 (aspect), X_2 (position on slope), and X_3 (percent slope). Elimination of soil depth as a separate variable resulted in an equation almost as precise as the original one. This does not mean that soil depth has little effect on site index. On the contrary, it is a most important factor, as is shown in figure 27. It can be omitted from the equation without much loss of precision only because of the close correlation that exists between soil depth and the slope factors. The shorter equation is: $Y = 1.9375 - 0.07036\ X_1 + 0.00132\ X_2 - 0.00267\ X_3$. The use of an equation without soil depth permits much quicker and easier measurements of the variables in the field.

A supplemental site study on the limestone-derived Belmont soils was recently completed for the same area covered in the

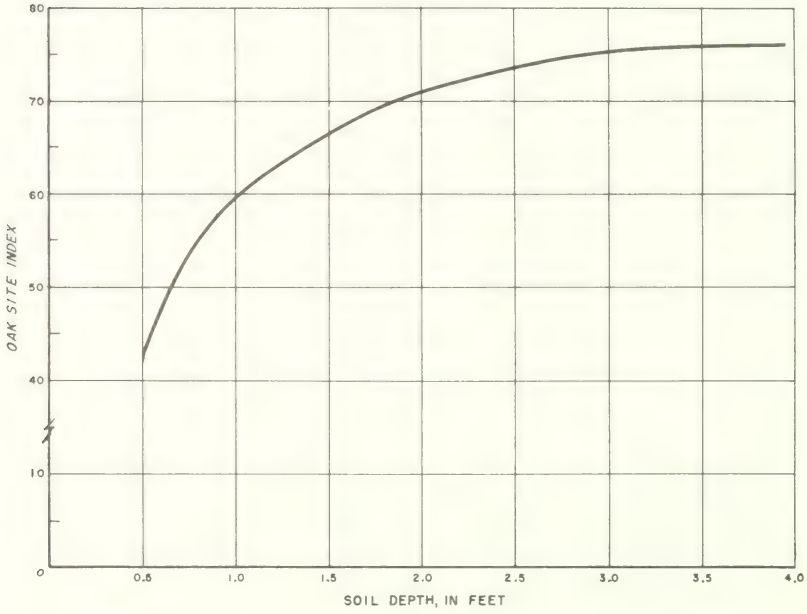

Figure 27.—Site index in relation to soil depth. Other factors are constant: 30-percent slope, one-third distance from bottom, aspect southeast.

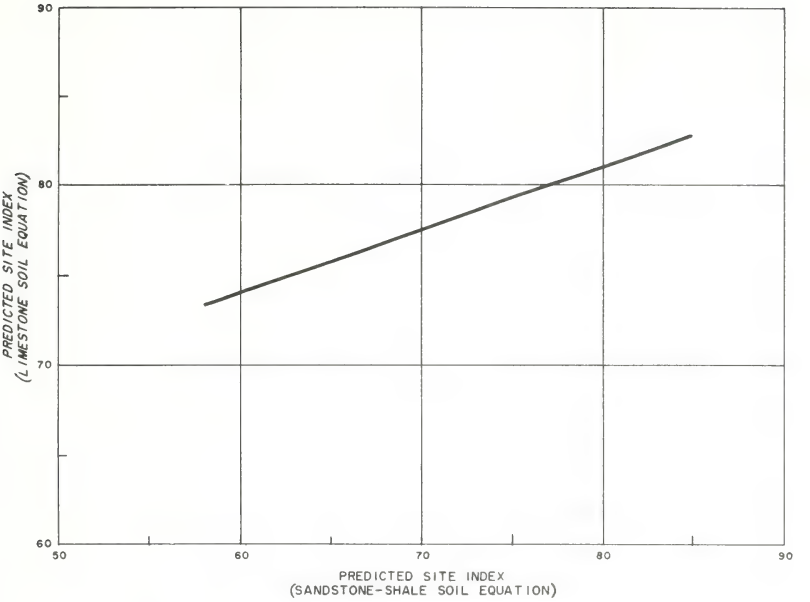

Figure 28.—Relationship between sandstone-shale soils and Belmont limestone soils, for oak site index.

original study on sandstone and shale soils. On the Belmont soils oak site indexes showed a unique relationship to site indexes on the sandstone and shale soils. For the combinations of topography and soil depth that are associated with the poorer sites, the Belmont soils had considerably higher site indexes than the sandstone-shale soils. For example, in situations where sandstone-shale soils had an index of, say, 60 feet, Belmont soils in similar situations had an index of about 74 feet. However, as the location and soil-depth factors became more favorable, the influence of the soil itself declined and, on the excellent sites, was insignificant. For combinations of topography and soil depth favorable enough so that the site index would be 83 feet on sandstone-shale soils, the index would be no better on Belmont soils (fig. 28). A publication on this work is in preparation.

Two additional oak site studies now are under way in the area east of the main ridge of the Alleghenies in West Virginia and Western Maryland. One concerns the same group of sandstone

and shale soils that was studied originally in the Plateau and Mountain sections. The other deals with the Ashby soils, which also are derived from sandstone and shale but seem to support distinctly poorer tree growth than other soils in the region. For that reason, we are examining the Ashby soils separately.

SPECIES-CONVERSION STUDY

It is generally believed that our northern Appalachian forests contained considerably more white pine in the past than they do now. Heavy early cutting and fires probably reduced this species. There are indications that, on poor sites, white pine will grow better and produce more high-quality timber than the oaks and other hardwoods that now occupy such sites.

In 1954 a small study was started to: (1) identify the sites where white pine should be favored or could profitably be introduced in mixture with the hardwoods; and (2) to determine, by oak site-index classes, the cultural measures needed to establish white pine and to enable it to compete successfully with the hardwoods.

The 6-year results of this study (*40*) are in accord with findings from other places in the range of white pine (*9, 20*). These results show that on fair to good sites white pine should not be introduced because of the intense competition from the hardwood undergrowth; whereas on poor sites, where the undergrowth typically is less aggressive, pine can be planted with good chances for success (figs. 29 and 30). The results indicate further that:

- Where 50-year or older hardwood stands occupy land of site index 40 to 60 for oaks, white pine can be planted with reasonable success after a heavy cutting of all hardwoods down to about 5 inches d.b.h. Trees above about 5 inches d.b.h. that are not harvested should be girdled or poisoned. A mixed white pine-hardwood stand should result, with a fair number of the planted pines in the dominant canopy.
- From 3 to 5 years after planting, a release from hardwood

Figure 29. — Planted white pine on site index 60 for oaks. Here hardwood brush is competing strongly against the pine.

Figure 30.—On oak site index 43, this planted white pine is outgrowing the competing hardwood brush.

sprouts will, in most instances, increase survival and growth of the pines. However, a fair proportion of the pines should come through without release.

- If little or no after-logging release is to be done, the upper marginal site for the introduction of white pine into hardwood stands appears to be between site indexes 50 and 60. This study did not include the more intensive types of release treatments. However, it may be pointed out that, by proper use of herbicides, the marginal site index could probably be somewhat higher.

Information on species conversion on sites poorer than site index 40 for oak is not available from this study. Such sites may not be good enough for white pine, and on them perhaps conversion should be based upon less demanding species, such as Virginia pine. More research is needed on these extremely poor sites.

REGENERATING RED SPRUCE SITES

In 1940-41 the Southeastern Forest Experiment Station put in seeding and planting experiments on a number of former red spruce sites in the Appalachians, including several locations in northern West Virginia. We re-examined some of the test plantings and seedlings in our territory in 1950, and reported on them in 1954 (*1*).

The areas involved were high-country sites where the virgin spruce stands had been clearcut and burned around the turn of the century. Several experiments, all concerned with seedling survival and growth, were begun. One dealt with the effects of vegetative cover on planted and seeded red spruce and red pine; another dealt with the effects of release cuttings on established red spruce, and another experiment compared seeded and planted red spruce and southern balsam fir (*Abies fraseri*) on rocky sites where most of the organic soil had been burned off. Although the results were far from conclusive, the study produced some worthwhile information:

- Bracken fern interfered more seriously with planted red spruce than with red pine. Spruce competed better with over-topping woody shrubs and trees.
- Early release of red spruce increased survival but had little effect on height growth.
- Direct seeding failed with all species. On the rocky sites the catches from direct seeding, although poor, were somewhat better for the fir than for the spruce.
- On the rocky sites, planted spruce survived better than planted fir, but the fir grew faster.

WHITE PINE PLANTATION THINNING

In a fast-growing white pine plantation (the Clover Run plantation) on the Monongahela National Forest, near Parsons, a small study is under way to determine the approximate level of stocking for maximum board-foot volume yields. Averaging about 17,000 board feet per acre at 27 years of age, with trees 70 to 75 feet tall (site index 100), this probably is one of the best existing plantations of eastern white pine (*2, 4, 41*).

Figure 31.—A light thinning in the Clover Run white pine plantation.

Three treatments have been applied to twice replicated plots: (1) control—unthinned; (2) thinned from below, leaving sufficient trees so that crowns touch but do not overlap; (3) thinned in general from below but removing enough trees in the dominant canopy so that crowns of residual trees are approximately 5 feet apart (fig. 31). Ten permanent sample trees were designated on each plot to provide data on height and d.b.h. growth of individual trees. Stands will be thinned at 5-year intervals.

PLANTING OF STRIP MINE SPOIL AREAS

Stripping for coal has drastically disturbed the surface of many forested areas in West Virginia (fig. 32). The resultant spoils have created problems of water pollution, wasted land resources, and dreary repellent landscapes.

Although revegetation to trees appeared to be the best form of land use for most of the stripped areas, no comprehensive studies of tree establishment on strippings in West Virginia had been made up to 1949. Accordingly, a survey type of study was made at that time to assemble information on the possibility of planting trees on the spoil banks. The study included examination of such earlier plantings as could be found, but did not include planting tests. Results of this study were published in 1951 (*12*). Some findings were:

- Ungraded or partially graded spoils appeared to offer better survival and growing conditions for trees than completely graded spoils.
- Revegetation was definitely related to acidity of the spoil material. Where pH values were lower than 4.0, less than 1 percent of the area had revegetated naturally; where the values were 4.0 or higher, herbaceous and woody species generally were becoming established in some abundance.
- Except where limited by excessive soil acidity, natural revegetation increased with age of the spoil area. Average density of cover for 1-year-old ungraded spoils was about 8 percent,

Figure 32.—An area disturbed by strip mining.

and for 3-year-old spoils about 48 percent. After 3 years the rate of increase tapers off, but most 5-year spoils were more than 50 percent covered. In contrast, graded spoil areas showed only 2 percent cover at 1 year and 12 percent at 3 years.

- As a result of this survey and of planting studies in nearby states, the following tree species were recommended for plantings on West Virginia mine-spoils of pH 4.0 and higher:

Conifers	*Hardwoods*
Red pine	Black locust
Pitch pine	Yellow-poplar
Jack pine	Red maple
Virginia pine	Sycamore

Hybrid-poplar clonal test-planting on acid strip-mine spoil banks at high elevations in West Virginia gave poor results after 11 years. Liming resulted in some—not much—improvement in survival and growth.

In 1958 and 1959 the Elkins project participated, along with The Pennsylvania State University, in a study of mine-spoil plantings in Pennsylvania (5).

GENETICS

Genetics research has not been a specific part of the program here. However, in the Northeastern Station's over-all testing program for hybrid poplars (Populus), 50 clones in replicated plantings have been under observation near Parsons for 11 years. Seven of the clones appear to have done well enough to be recommended for planting under soil and climatic conditions similar to those at the West Virginia test area (3). These seven clones all grew at average rates of 3.6 feet per year or better. They are all hybrids of *P. maximowiczii.*

The Northeastern Station also is conducting a white pine provenance test in which one of the field plantings is near Parsons. Growth and survival of seedlings from many areas are being studied in this test.

THE BLUE CREEK EXPERIMENTAL FOREST

An agreement, entered into in 1957 by the Union Carbide-Olefins Company and the Northeastern Forest Experiment Station, led to the establishment of the Blue Creek Experimental Forest, 25 miles from Charleston, in southern West Virginia. Climate, sites, and species composition of the stands there are more representative of southern Appalachian mountain hardwood forests than the stands on the Fernow. The Experimental Forest, comprising some 2,500 acres of company land, will be used in a joint research program. So far, three timber-management studies have been started.

One study, involving several different methods of partial cutting, has been begun on 5-acre replicated plots on an excellent site; it is to be extended later to a nearby area of poorer site. The main independent variables are site and treatment. Growth, reproduction characteristics, and log quality are the principal dependent variables.

Work is under way on a replicated plot study on an excellent site to compare production at two growing-stock levels: 40 and

80 square feet of basal area per acre in trees over 9.0 inches d.b.h.

The third study is a thinning test in even-aged stands of mixed basswood and yellow-poplar: replicated plots will be thinned to 60 percent of full stocking at 10-year intervals by two methods—low thinning and selection thinning. The dependent variables are volume produced and log quality. Individual tree growth and quality development will be studied on a number of sample trees.

FOREST-PATHOLOGY INVESTIGATIONS

In 1961 forest pathology investigations were begun at the Elkins unit. Currently under way, or planned, are studies on: *Fomes annosus*[5]—its occurrence and treatment; the effectiveness of actidione in combating chestnut blight in sprouts of native chestnut; the transmission of the oak wilt pathogen; the effectiveness of antibiotic treatments (phytoactin) on resistance of white pine seedlings to blister rust infection; and the relationships of various factors to the decline of red and scarlet oaks.

Research Aspects

Philosophically, our program has three aspects:

1. *Research in depth, where the tools of management are studied and defined.* Stand and individual-tree growth and quality studies, site-capability investigations, the relationship of cutting methods and site to reproduction, studies of the factors affecting road erosion, and development of methods of analysis of streamflow are a few examples.

2. *Testing of hypotheses where various types of forest land management are practiced and compared on a large scale.* The compartment-management studies (for both timber and water) exemplify hypothesis testing.

[5]*Fomes annosus* is a fungus that causes root and butt rots in conifers. This is a serious menace to conifer plantations.

3. *Demonstration, where certain forest practices are carried out, as the name implies, primarily for demonstration rather than experimental purposes.* The small forest properties and the management unit fall in this category.

Many studies overlap into two or all three of the above categories. For instance, the compartments designed for hypothesis testing are the framework for much research in depth and also provide excellent demonstration areas. The small forest properties and the management unit, organized primarily as demonstration areas, provide the data and the locale for economic studies. The hypothesis testing and demonstration aspects of the early research program played an important role in arousing general interest in better forestry in this area, and they still do.

With the increasing interest in the practice of more intensive forestry and the rising awareness that forestry has a multiple-use role to play in resource development, emphasis in the research program has shifted over the years from answering questions in the realm of "What happens?" to those in the "Why?" and "How?" realm. This means that more attention today is being given to research in depth.

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SITE INDEX

of New Jersey Sweetgum Stands Related to Soil and Water-Table Characteristics

■

John J. Phillips & Marco L. Markley

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SITE INDEX

of New Jersey Sweetgum Stands Related to Soil and Water-Table Characteristics

John J. Phillips & Marco L. Markley

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Introduction

AS FOREST management becomes more intensive, there is increasing need for knowledge of the differences in the productiveness of individual land areas or sites. For example, highly productive forest lands justify far more investment in cultural measures than do those of low productivity or, more specifically, conversion from stands of low-value species may be economically feasible on the better sites, but not on the poor sites.

PREVIOUS STUDIES

Very little work has been done on species typical of wet sites in the Northeast. However, in the South, Broadfoot and Krinard (1959) related a number of soil characteristics and soil types to the site index of sweetgum. For soils outside the Missisippi River flood plain, they found an increase in site index with increased exchangeable potassium and decreased clay content, both sampled in the 3- to 4-foot soil layer.

On sites adjacent to reservoirs with fluctuating levels in Tennessee, sweetgum plantations grew best on soils with deep surface layers and permeable subsoils, poorest on poorly drained sites with

compact subsoils (Silker 1948). Minckler (1946) also found that sweetgum grew better on friable soils than on plastic ones.

In Maryland, Trenk (1929) observed that the best growth of sweetgum occurred on alluvial sites and on wet soils high in clay, the poorest growth on well-drained clay or gravelly-clay soils.

GENERAL APPROACHES

The usual method of determining site productivity of forest land is to first obtain the heights and ages of several dominant and codominant trees and then read the site-index value (height of dominant trees, in feet, usually at age 50) from a set of existing site-index curves for a particular tree species. However, all land areas are not now occupied by stands of trees suitable for use in making a determination of site index. And it is desirable to be able to estimate site index from observations or measurements of certain features of the land itself—usually soil and topography.

Two approaches are used to establish relationships between site index and the soil and topography. One approach is to correlate site index with various measurable factors of the soil and topography, such as soil texture and position on slope. The other approach is to determine the average site index for each of the soil types on which a tree species commonly occurs.

In the study reported in this paper, both approaches were used in sweetgum (*Liquidambar styraciflua* L.) stands on the Coastal Plain of New Jersey. There sweetgum is a prized species: it, yellow-poplar, and oaks are the valuable components of forest stands on the more productive sites. On these soils, sweetgum frequently forms relatively pure stands in abandoned fields or pastures. And local basket mills rely heavily on sweetgum logs for their veneer.

Study Area

In New Jersey, sweetgum stands are usually confined to the Coastal Plain. However, the species does extend up some of the river valleys to the Piedmont (Stone 1911), where sweetgum usually occurs as scattered trees in stands of other species. Sweetgum is generally absent from the coarse sand and gravel deposits of the Pine Region, but occasional clumps or stands occur in the Coast District (fig. 1) delineated by Stone.

Pure or nearly pure stands of sweetgum are common in the inner Coastal Plain, particularly in portions of Middlesex, Monmouth, Burlington, and Salem Counties. Such stands are nearly always even-aged and of old-field origin, having developed for the most part on soils too wet to be kept in agriculture. Agricul-

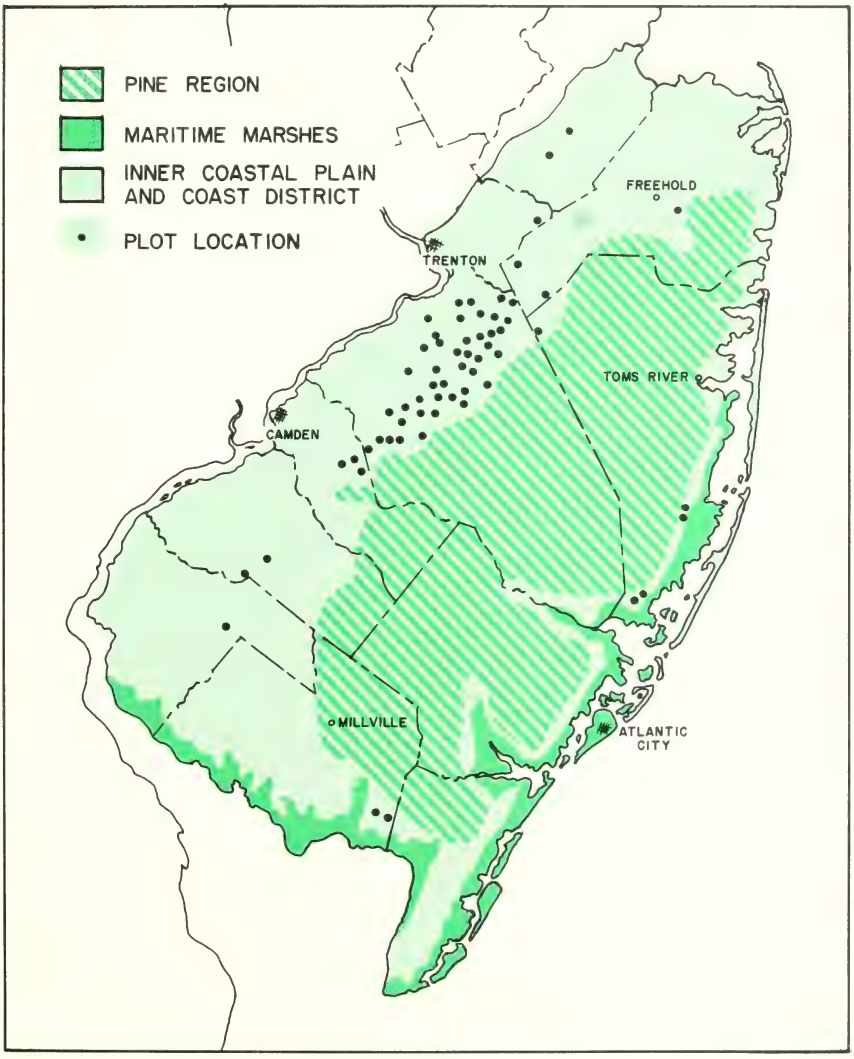


Figure 1. — The subdivisions of the New Jersey Coastal Plain (after Stone 1911), and the plot locations of the sweetgum site study.

ture in the inner Coastal Plain is intensive, and most woodlots there are small and scattered.

Topographically, the New Jersey Coastal Plain is more rolling than most of the rest of the Atlantic Coastal Plain. Soils in the inner Coastal Plain vary in texture from sands to clays. Where well-drained, the soils are intergrades between the Gray-Brown Podzolic and Red-Yellow Podzolic soil groups. Where poorly or very poorly drained, the soils are Low-Humic Gleys or Humic Gleys. Type and age of parent soil materials vary from the older beds of glauconitic, Tertiary, and Cretaceous deposits near the Delaware River to the younger beds of lacustrine, aeolian, and alluvial deposits of Pleistocene origin. The latter deposits overlie the older beds in many places.

STANDS

All of the sweetgum stands studied were even-aged, originating in abandoned fields (fig. 2). Dominant and codominant trees were 30 to 65 years old, with a maximum range in age of 6 to 8 years within individual stands. All stands were dense, and the basal areas ranged from 117 to 240 square feet per acre.

In composition, the stands were fairly uniform on all plots. Sweetgum made up more than 90 percent of the overstory canopy, with some red maples in the intermediate and overtopped crown classes. In some stands a few pin oaks were dominant along with the sweetgums. However, both sweetgum and pin oak were

Figure 2. — A typical even-aged sweetgum stand on a Weeksville fine sandy loam soil in New Jersey. This stand is 41 years old and has grown more than 100 merchantable cubic feet per acre per year. Its dominants are about 11 inches in diameter breast high.

sparsely represented or absent in the reproduction, except near the edges of the stands. Red maple predominated in the reproduction, although some stems of other species also occurred, chiefly willow oak, swamp white oak, northern red oak, holly, ash, beech, dogwood, and sassafras. Characteristic shrubs were southern arrowwood (*Viburnum dentatum*), spicebush (*Lindera benzoin*), high-bush blueberry (*Vaccinium* spp.), and sweet pepperbush (*Clethra alnifolia*); but poison ivy (*Rhus radicans*) was even more common. Wild garlic (*Allium* spp.) was the most prevalent herb.

SOILS

Soils were predominantly wet: poorly drained and very poorly drained soils made up 84 percent of the total number of plots. This high proportion was apparently due to two factors: (1) sweetgum needs moist or wet sites for successful establishment and rapid growth, and (2) wet soils are usually the first to be abandoned from agricultural use.

As might be expected, all of the study areas were in relatively flat areas or small depressions. Slopes generally averaged less than 1 percent, with a maximum of 4 percent.

Nearly all of the stands studied had mineral soils. Organic soils supporting sweetgum were found in only three stands, and only one of these stands was stocked well enough to be included in the study. This area had a shallow layer of muck, but its drainage had been improved by a nearby outlet ditch.

Most of the sites had surface drainage ditches, relics from their use as fields. The ditches varied in their state of repair and efficiency. Some of them, as the one in the muck area, appeared to be at least partially effective in lowering the groundwater table. Others seemed too poorly maintained to have any appreciable effect, especially in the heavy-textured soils. And there were no detectable relationships of site index to distance from ditches or to their depth.

Study Methods

Three to ten plots, each 0.1 acre in size, were established on each soil series commonly supporting sweetgum stands. Several plots were also installed on the less common sweetgum soils to determine what soil characteristics affected site index in these particular areas. A total of 61 plots were included in the study.

Each plot had to meet certain requirements. Soil conditions had to be relatively uniform, uniformity being determined from at least three auger holes. The stand had to be even-aged, and had to contain at least 10 dominant or codominant sweetgums 30 to 65 years old. Sampled trees had to be of seed origin, and free of any apparent damage by fire, grazing, dieback, or blight.

Total heights of 10 dominant and codominant trees on each plot were measured with a Haga altimeter, and increment cores were taken at breast height. These cores were dyed with a phloro-

glucinol solution to make the annual rings more prominent (Patterson 1959). Ring counts were made under a low power (12×) microscope, and 3 years were added to obtain total age from seed. From the height and age data of each plot, a site-index value was obtained by using curves (base age of 50 years) derived from Trenk's (1929) tables. Data from the present study were used to construct height-age curves by site classes, but these were so similar to Trenk's data that his were used.

A detailed soil description was prepared for each plot; this included depth measurements that were used in later statistical analyses. In addition, soil samples (each a composite from three holes) were taken of the surface 6-inch horizon and of the B_2 horizon. Sampling for the latter started 2 inches below the top of the B_2, and usually extended 6 inches more in depth.

The soil samples were analyzed for texture and reaction. Texture samples were analyzed by the Bouyoucos hydrometer method, as modified by Wilde and Voigt (1955)—except that the samples were allowed to rehydrate overnight in the dispersing solution. The selection of this period was arbitrary, since the minimum time necessary was unknown. However, tests with plastic soils gave higher clay values with overnight rehydration than with the usual 15-minute treatment. The samples of the B_2 horizons were separated into four textural fractions: coarse sand (2.0 to 0.25 mm.), fine sand (0.25 to 0.05 mm.), silt (0.05 to 0.002 mm.), and clay (less than 0.002 mm.). Samples of the A-horizons contained too much organic matter to permit easy separation of silt from clay; so this was not done.

Soil reaction, acidity in all cases, was determined by using a simple colorimetric pH kit. Generally the soils were rather acid. Surface soil pH averaged about 4.6, and subsoil pH about 4.5. The range of pH in the surface soil was from 4.0 to 5.4, and in the subsoil from 4.0 to 6.2.

Groundwater wells were established in three to five plots on each of the nine principal soil types. Each well was installed by placing a 5-foot length of downspout in an auger hole of 3-inch diameter. A No. 2 tin can was placed on top to keep foreign material out of the pipe. Wells were measured five times during the 1960 growing season so that average, high, and low water depths could be determined for each plot.

Groundwater depths cannot be easily used in site-index prediction, since they require at least a year's measurements, but they were useful in providing information on relationships between the groundwater regime and sweetgum growth.

Results

WELL MEASUREMENTS AND SITE INDEX

Water-table relationships alone could probably be used to explain about half of the variation in site index found in New Jersey sweetgum stands. At least for the 27 wells used in the analysis (3 were discarded because of artesian properties and lack of complete data), the resulting equation based on average depth and maximum fluctuation of water table during the growing season explained more than half of the variation in site index (fig. 3).

The highest site-index values were correlated with an average depth of 20 inches to free water, and with little fluctuation in the level of the water table. The lowest values were correlated with very high or very low water tables and with fluctuations of 2 feet or more. As figure 3 indicates, fluctuations (range in depth to free water) greater than 24 inches have little effect on site index; here other soil properties appear to become more important than water-table fluctuations, although average depth to water is still important.

Recent alluvial deposits within the Delaware Valley provided the most consistent data, and had consistently high site-index values. Such areas are composed of mixed materials that are being currently deposited by nearby streams. Depth to the water table is usually related to the height of the land surface above the stream, and it fluctuates little because the level of the water table is in turn controlled by the stream.

One exception occurs when this alluvial material is underlain by fine-textured, slowly permeable layers. Here the water table may be above the stream surface; and fluctuations in the depth of the water table are affected by the size of the watershed area.

In the mature hydromorphic soils, with well-developed horizons and no recent alluvial deposits,[1] the correlation between site index and water-table conditions was affected by the type of subsoil. The correlation was better for soils having friable subsoils than for those with plastic subsoils, although both followed the same general trend. As a rule, site index seems less dependent on water-table levels in soils having plastic subsoils than in those with friable subsoils.

[1] This definition of mature soils agrees with that given in the U. S. Dept. Agr. Yearbook of Agriculture, 1938: "A soil with well developed characteristics produced by the natural processes of soil formation, and in equilibrium with its environment."

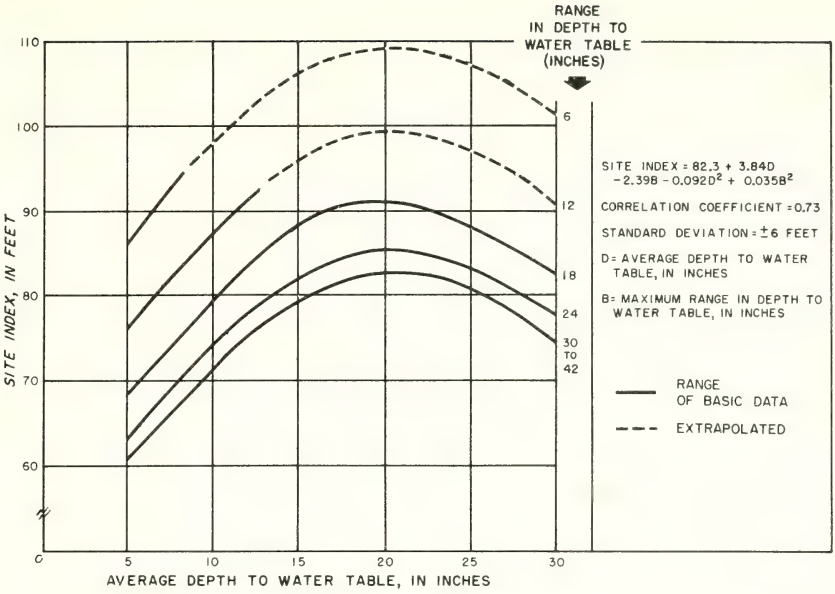


Figure 3. — Site index for sweetgum, as related to fluctuation in depth to water table during the growing season and to average depth to the water table.

Observations during the study indicate that the depth of sweetgum rooting is affected by subsoil consistence and by summer water levels. Rooting was observed to be deeper in soils with plastic subsoils than in those with friable ones, and to increase with increased depth of summer water levels. The rooting depth was little affected by high water during the winter, but of course nearly all the study areas had high water levels then.

SOIL FACTORS AND SITE INDEX

Equation for Mature Soils

A number of soil characteristics or factors were analyzed to determine their degree of correlation with site index. Of these, texture and thickness of the B_2 horizon, along with a factor indicating permeability, gave the best correlation for mature soils.

There was a small, but significant, negative correlation between site index and age before removing the effects of soil factors. After they were removed, plotting age against the deviations from the regression failed to reveal any further correlation. The appar-

ent relationship of age and soil can probably be explained by the fact that some of the soil factors, especially texture, influenced the timing of field abandonment from agricultural crop production.

The final equation relating soil factors to site index is:

$$\text{Site index} = 26.4 + 0.49X_1 + 1.49X_2 - 0.015X_3 + 0.78X_4 - 0.023X_5 + 1.38X_6 - 0.049X_7$$

where:

X_1 = per cent clay in the B_2 horizon.
X_2 = percent fine sand in the B_2 horizon.
$X_3 = (X_2)^2$.
X_4 = difference between percent silt plus clay in the B_2 horizon and percent silt plus clay in the A horizon.
$X_5 = (X_4)^2$.
X_6 = positive difference between 12 inches and the thickness of the B_2 horizon in inches.
$X_7 = (X_6)^2$.

Table 1 gives readily available and usable site-index values derived from the final equation. With this table and appropriate knowledge of the soil factors or variables of a given area, the site index can be estimated.

The multiple correlation coefficient for the equation is 0.817, and the standard error of estimate is $\pm$ 5.7 feet. The equation and the variables are all highly significant. Of the four variables, clay and fine sand were the most important, together removing about 50 percent of the total variation. However, each variable was significant at the 1-percent level when the effects of the other three were eliminated.

Site index increased linearly with clay content of the B_2 horizon throughout the sampled range of 5 to 55 percent. The increase was about 5 feet for each 10-percent increase in clay. The difference in site index at the two extremes was about 24 feet.

The correlation between site index and the fine sand of the B_2 horizon was curvilinear (fig. 4). Site index increased as the proportion of fine sand increased from 15 to 50 percent, although the rate of increase declined above 40 percent. Between 50 and 70 percent fine sand, the site index declined. The increase in site index between 15 and 50 percent of fine sand in the B_2 horizon was 18 feet; and the decrease in site index between 50 and 70 percent was 7 feet.

The inclusion of separate values for clay and fine sand gave a significantly better relationship than the use of silt-plus-clay content, which also had a curvilinear relationship with site index. The proportions of silt and of coarse sand, as well as the product

Table 1. — *Predicting sweetgum site index, in feet, on mature soils in the New Jersey Coastal Plain*[1]

A

Fine sand in B_2 horizon (percent)	Clay content of B_2 horizon, in percent—						
	5	10	20	30	40	50	55
15	48	50	55	60	65	70	72
20	53	55	60	65	70	75	77
25	56	58	63	68	73	78	80
30	60	62	67	72	77	82	84
40	65	67	72	77	82	87	89
50	66	68	73	78	83	88	—
60	64	66	71	76	81	—	—
70	59	61	66	71	—	—	—

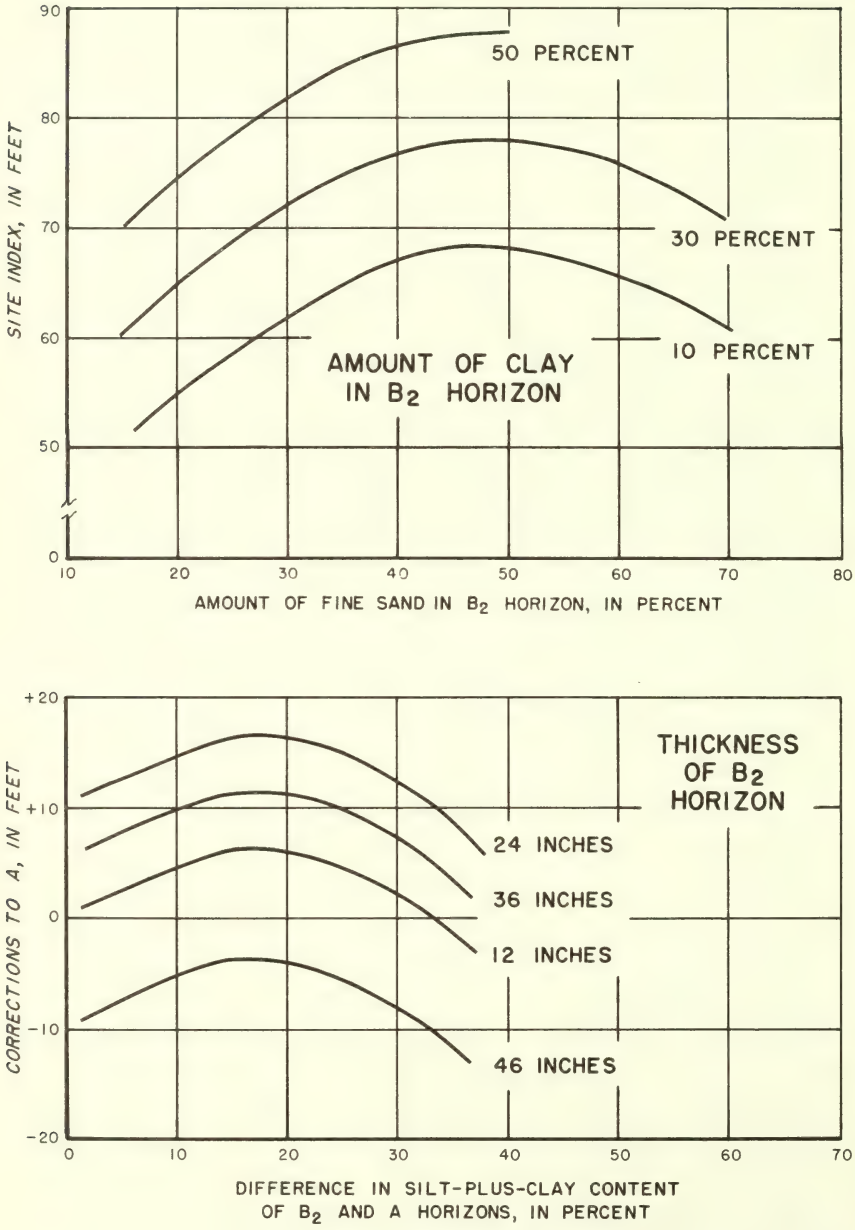
B

Thickness of B_2 horizon[2] (inches)	Difference in silt-plus-clay content of the B_2 and A horizons, in percent									
	1	5	9	13	17	21	25	29	33	37
6	7	9	11	12	13	12	11	9	7	3
8	6	8	10	11	12	11	10	8	6	2
10	4	6	8	9	10	9	8	6	4	0
12	1	3	5	6	7	6	5	3	1	−3
14	4	6	8	9	10	9	8	6	4	0
16	6	8	10	11	12	11	10	8	6	2
18	7	9	11	12	13	12	11	9	7	3
20	9	11	13	14	15	14	13	11	9	5
22	10	12	14	15	16	15	14	12	10	6
24	11	13	15	16	17	16	15	13	11	7
26	11	13	15	16	17	16	15	13	11	7
28	11	13	15	16	17	16	15	13	11	7
30	10	12	14	15	16	15	14	12	10	6
32	8	10	12	13	14	13	12	10	8	4
34	7	9	11	12	13	12	11	9	7	3
36	6	8	10	11	12	11	10	8	6	2
38	4	6	8	9	10	9	8	6	4	0
40	1	3	5	6	7	6	5	3	1	−3
42	−2	0	2	3	4	3	2	0	−2	−6
44	−5	−3	−1	0	1	0	−1	−3	−5	−9
46	−9	−7	−5	−4	−3	−4	−5	−7	−9	−13

[1] First obtain base value in A, then correct as indicated in B. Final site index is the result of adding these two values.

[2] Measured to the bottom of the B_2 or to a depth of 55 inches.

Figure 4. — Effect of certain soil factors on the site index for sweetgum.



of fine sand and clay separates, lacked significance after the individual effects of clay and fine sand were removed.

The difference in the silt-plus-clay contents of the A and B_2 horizons is an index of permeability in the sampled soils. In these, the B_2 horizon usually has a higher content of silt and clay, and where the textural change is very great, a zone of perched water occurs above the less permeable horizon.

A change in texture between the A and B_2 horizons appears favorable for the growth of sweetgum, with a 17- or 18-percent difference being optimum—resulting in an increase of about 7 feet in site index (fig. 4). Beyond this optimum, site index declined. When the difference between the A and B_2 horizons in their silt-plus-clay content reached 38 percent—the maximum found in this study—the site index was 10 feet less than at optimum.

The relationship between thickness of the B_2 horizon and site index is not clear. Where the B_2 horizon was thin, site index was generally good, everything else being equal. However, as the thickness of the B_2 horizon approached 12 inches, site index declined. Then, with further increases in B_2-horizon thickness, site index increased, reaching an optimum at 24 to 28 inches in horizon thickness. Still thicker B_2 horizons were associated with poorer sites. An increase in thickness of the B_2 horizon from 6 to 12 inches was correlated with a decrease of 6 feet in site index; that from 12 to 24 inches, an increase of 10 feet; and that from 28 to 46 inches, a decrease of 20 feet.

Other soil-depth factors (thickness of A_1 horizon, total A-horizon thickness, depth to least permeable layer, depth to mottling, depth to gley layer, and solum thickness) were not significantly related to site index. Nor was there any discernible relationship between site index and soil pH.

Equation Not Applicable to Recent Alluvial Deposits

The site index for sweetgum growing on recent alluvial lands cannot be estimated by using the above equation. On recent alluvial deposits, site index apparently depends primarily on water-table relationships and less on soil texture. Lands having relatively fine-textured glauconitic alluvial deposits showed little range in site index even with considerable variation in texture. Site index on these lands was always higher than it was on coarse textured, non-glauconitic deposits. However, the non-glauconitic

deposits had a higher site index than soils of a similar texture that had lower summer water levels.

Effect of Water Table on Equation

Although the above equation was satisfactory for most of the mature soils, on certain areas it was not accurate, largely because of differences in water-table characteristics. Apparently where water tables are high and show little fluctuation, site-index estimates on mature soils might be improved by basing the estimates on both water-table relationships and the soil factors used in the equation.

Also, because the soil-factor equation was derived principally from a population of wet soils, it should not be applied indiscriminately to dry sites. While the equation appeared to estimate site index well for the few drier sites studied, it may not be applicable on all other dry sites. For example, Trenk (1929) observed poor sites for sweetgum on well-drained clays in Maryland, whereas the equation from this study would probably indicate that any soil high in clay content should be a good site for sweetgum.

SOIL SERIES AND SITE INDEX

Soil series recognized by the National Cooperative Soil Survey appear to be a fairly good way of estimating the site index for sweetgum in this study. For site-index values, sufficiently replicated by soil series, an analysis of variance gave a highly significant F value. The mean site index, range in site index, and number of plots are given for each soil in table 2. Soils that were sampled by three or more plots are described briefly in the Appendix.

Site index varied more on certain soil series than it did on others. The least variation encountered, 2 feet, was on poorly drained silty Othello soils; somewhat greater variation, 9 feet, occurred on the Adelphia and Bayboro soils and on recent alluvial glauconitic deposits. The most variation, 21 to 23 feet, occurred on Keansburg soils and on those areas with a field designation of Bustleton soils.

There appear to be different reasons for the variation in site index found within the various soil series. For example, one Bustleton plot had a much thicker B_2 horizon than the others sampled; the remainder of the plots on this soil were more nearly uniform in site index. The variation in site index on Keansburg soils seems to be due to texture variation and, to some extent, to ground-water differences.

Table 2. — *Site index for sweetgum by subsoil texture, soil series, and drainage class*

Soil groups, by subsoil texture[1] and soil series	No. plots	Site index,[2] by drainage class				
		Well drained soils	Moderately well drained soils	Somewhat poorly drained	Poorly drained soils	Very poorly drained soils
MATURE SOILS						
1. Sand-loamy sand:						
Klej	1	—	—	75	—	—
Rutlege	1	—	—	—	—	60
2. Sandy loam:						
Nixonton	1	—	85	—	—	—
Dragston	1	—	—	58	—	—
Fallsington	2	—	—	—	[3]61 (58-64)	—
Pasquotank	1	—	—	—	74	—
Keansburg	10	—	—	—	—	81 (69-92)
Weeksville	3	—	—	—	—	77 (71-86)
Pocomoke	1	—	—	—	—	62
3. Sandy clay loam-clay loam:						
Collington	1	78	—	—	—	—
Mattapex	1	—	83	—	—	—
Adelphia[4]	2	—	85 (81-89)	—	—	—
Adelphia[4]	3	—	—	81 (80-82)	—	—
Bustleton[5]	5	—	—	—	77 (63-84)	—
Othello	3	—	—	—	83 (82-84)	—
Rancocas[5]	5	—	—	—	—	83 (78-90)
Bayboro	5	—	—	—	—	87 (82-91)
4. Sandy clay:						
Colemantown	2	—	—	—	85 (81-92)	—
Matlock	3	—	—	—	—	72 (70-74)
RECENT ALLUVIAL DEPOSITS						
Glauconitic	6	—	—	—	—	89 (85-94)
Non-glauconitic coarse-textured	2	—	—	—	—	80 (77-82)

[1] The texture given is the average for the B horizons of all plots within the group.

[2] Standard deviation of approximately 7 feet at 50 years for all series with replicated plots.

[3] Figures in parentheses show the range of site index found, and the figure in front of the parenthesis is the mean site-index value for all plots of that soil series.

[4] Adelphia soils may be either moderately well drained or somewhat poorly drained.

[5] Bustleton and Rancocas are temporary field names, not yet approved.

To determine whether or not the soil-series classification included any important factors not considered in the regression equation, the deviation between actual site index and predicted site index (from the equation) was obtained, and then the mean deviation was computed for each soil series. In all but one of the soil series, the mean deviations were ± 3 feet or less, and the amount of variation was not related to mapped drainage class or surface texture.

Measured site index differed consistently from the predicted site index in only one soil—the moderately well-drained Adelphia. This soil was represented by only two plots, both of which were underestimated by 5 feet. By contrast, the predicted and actual site-index values agreed very well on the somewhat poorly drained Adelphia plots. The authors have no explanation for this discrepancy.

Two of the most extreme deviations from the regression estimate were within the Keansburg soil series. Site index for 8 of the 10 plots on this soil was estimated quite well. However, one plot had a site-index value 9 feet above the estimated value, and the site index of the other plot was 12 feet below the estimated value. Both of these deviations are related to ground-water influences. The first plot, wtih a measured site index value above the predicted value, was located about 50 feet from a stream, and therefore had some of the favorable ground-water characteristics of an alluvial site. The other plot, with site index lower than the predicted value, had an excessively high water table. During the 1960 period of measurement, the average depth to water on this plot was only 1 inch, with a range in depth of 7 inches. In such areas, ground-water conditions appear to be more important than soil properties.

The equation estimated site index fairly well on the glauconitic soils, though the soils do present a problem in texture analyses. Under complete dispersion, textures of highly glauconitic soils seem predominantly clay, but under natural conditions the clay micelles are partially aggregated into sand-size particles that are dispersed only with difficulty. Hence results from texture analyses of these soils depend on the severity of dispersion techniques. In this study the apparent texture in natural soils seemed more important than true texture determined from complete dispersion, so samples of glauconitic soils were treated in the same manner as the others. The results indicate that the use of apparent texture was justified.

Values of table 2 should not be applied indiscriminately to

soil series of the same name outside New Jersey. Even though the same name is used, the range in texture and other characteristics found within a soil series may be somewhat different for widely separated areas, particularly in the proportion of fine sand. Both the data of table 2 and the soil-factor equation are considered most applicable to New Jersey conditions.

Discussion

COMPARISON OF METHODS

Water-Table Measurements

For the most part the use of water-table data to predict site index seems impractical. Measurements would apparently have to be taken for several months, and data from one growing season would not usually be the same as those from another. Prediction of water-table depths and fluctuations by means of mottling or gleization patterns also seems impossible for the soils of this study. In certain soils the thickness of the mottled zone seemed to be correlated both with range in water-table depth and with site index. But in other soils slow internal drainage favored the development of mottling, while in still others no mottling was present even though the soils were quite wet. Gleization exhibited a similar lack of pattern for prediction purposes.

Such variation seems logical in view of present knowledge. According to the Russells (1954), mottling develops in sandy soils within the zone through which the water table fluctuates. Mottling is the result of alternate reduction and oxidation of iron and manganese. It does not develop below the dry-weather water table probably because little or no oxidation occurs, nor above the fluctuating wet zone because reduction does not occur. And, in some soils, iron and manganese are apparently present in too small amounts for mottling to develop even within the fluctuating water-table zone.

Soil Series vs. Soil-Factor Equation

For practical site-index predictions on some soils, either the soil series or the prediction equation seems adequate. However, within a soil series that has a wide range in site index, the equation approach will give more accurate estimates. Further investigation

of these soil series may provide improved correlation of site index with mapping units or the subdivisions of each series.

Statistically, there are two reasons why the equation gives better estimates than soil series. First, the equation has a smaller error of estimate; and second, its estimate is for a specific area. In contrast, the average value for a soil series, as given in table 2, is from the several sampled areas considered representative of the particular soil. The extent to which the average and range in site index reflect the total variation possible is questionable, particularly for the soils with three or less samples. In addition, of course, there are areas with soils gradational between series.

Soil series have one advantage not shared by the equation. Where soil maps are available, the occurrence of sweetgum on similar soils can be determined more readily by the practicing forester.

The use of soil series for predicting site index has been criticized on the grounds that there is often as much variation in the site index within a soil series as between two soils. As table 2 shows, there is indeed appreciable variation within certain series, as well as overlap between series.

However, foresters and landowners should still find the data for soils series to be of value. For example, by knowing the location of a sweetgum stand or of a possible planting site for sweetgum, and by using a soils map and the information in table 2 of this paper, they might determine that the soil was mapped as a Weeksville fine sandy loam with a site index between 71 and 86. For greater accuracy, a field trip to check on the exact identification of the soil series or to obtain data for the soil-factor equation would be necessary.

APPLICATION

Soil series or soil mapping units have a big advantage in application wherever soil maps are available. However, the user of these maps should remember that:

- Soils are gradational, and different soil scientists may differ in their classification of intermediate soils;
- Where soil bodies are small, they may not be shown on soil maps because the scale limits the detail that is possible. And, under the usual standards followed in soil surveys, 15 percent of a mapping unit may be composed of inclusions of other soils.

- Soil classification has improved over the years, and as a result, series names have changed. Older soil maps were made under different standards and at different intensities than modern surveys. Users of soil maps should seek the most modern survey available or a modern interpretation of early surveys.

The most accurate identification of a soil is, of course, given by an experienced soil scientist examining a specific spot.

Application of the soil-factor equation can be done in one of two ways: (1) by measuring the thickness of the B_2 horizon and by estimating texture values, or (2) by measuring the thickness of the B_2 horizon and running a laboratory analysis of samples of the A and B_2 horizons. In both cases the thickness of the B_2 horizon *within the top 55 inches of soil only* is measured.

In both applications of the soil-factor equation, soils should be examined at several points or areas within a stand. If appreciable changes in texture and other characteristics occur, the different areas should be treated separately, unless the areas are so small they can be ignored. At each point considered, measurements or samples should be taken in at least three spots.

If the samples are to be analyzed in the laboratory, it is suggested that the soil from three auger borings be composited and, if time permits, that two such samples be obtained. A similar number of measurements of the B_2-horizon thickness should be made. The A horizon should be sampled in the surface 6 inches. Sampling of the B_2 horizon should start 2 inches below its top and extend for 6 inches or to the bottom of the B_2 (whichever is less). Laboratory analyses should be for (1) silt-plus-clay content of the A horizon, (2) silt-plus-clay content of the B_2 horizon, (3) fine-sand content, and (4) clay content of the B_2 horizon. In these analyses it is not necessary to remove the organic matter. However, the same procedure used in this study should be followed, especially the same rehydration period.

An approximation of site index can be made by measuring the thickness of the B_2 horizon and estimating texture by feel. The procedure is as follows:

1. By feel, place the B_2 horizon in one of 5 texture classes: (1) sand or loamy sand, (2) sandy loam or loam, (3) clay loams (including sandy and silty clay loams), (4) sandy clay, and (5) clay. Assume that the respective clay contents are 5, 15, 30, 40, and 50 percent.

2. Assume that the fine-sand content is 30 percent for most soils. Increase or decrease this figure for specific areas as experi-

ence indicates, and as ability to estimate fine-sand content improves.

3. Assume that the difference in silt-plus-clay content of the B_2 and A horizons is 5 percent.

4. Measure the thickness of the B_2 horizon (in top 55 inches of soil).

5. Use table 1 to estimate site index at several spots in the specific area, and obtain an average value. If differences are large, consider different portions of the area separately.

Errors in these approximations are, of course, introduced by the assumptions and by the method of determining texture class. In plastic soils there is a tendency to overestimate the amount of clay: for example, to classify clay loams as clays. This, of course, results in overestimates of site index. The assumption on fine-sand content will cause overestimates on some sites and underestimates on others, if the 30-percent value is used. Assuming a 5-percent difference in silt-plus-clay content of the B_2 and A horizons will not usually introduce an appreciable error; however, estimates may be too high for soils with sandy A horizons or those high in glauconite.

Of course, where it is feasible and not too much trouble, the use of two or more methods of estimating site index is preferable in an area. For example, if the regression equation (with texture analyses) is used along with the average value for soil series, the two methods should give a very good estimate of the potential productivity of the site for sweetgum.

MISCELLANEOUS OBSERVATIONS

Observations made during the study indicate that:

- Sweetgum appears to grow slowly on muck soils, the estimated site index there being 40 to 65 feet. However, this estimate is based on a limited number of observations.
- On muck or very wet mineral-soil sites, trees near ditches were taller than those farther away, probably because they were growing on material removed in ditch construction or maintenance. The resulting slight elevation above the surrounding land would give the sweetgum there a greater depth to free water.
- Except for the effect just mentioned, the influence of distance from ditches on site index was not discernible.

- Although sweetgum tends to be shallowly rooted on wet sites, windthrow is not common except near the edges of stands.
- The maximum site index measured for sweetgum in New Jersey is 95 feet, appreciably less than the 120 feet found by Broadfoot and Krinard (1959) in the South.

Summary and Conclusions

In the New Jersey Coastal Plain sixty-one 0.1-acre plots were established in sweetgum stands to determine relationships between site index and soil series, and site index and individual soil factors. The results indicate that site index can be obtained satisfactorily either from a soil-factor equation or from the mean value of a soil series. However, the site index of individual areas may differ somewhat from the predicted value, because of certain soil characteristics and water-table relationships that cannot readily be accounted for. For example, as yet there is no way of using soil-profile characteristics to indicate accurately the groundwater relationships.

For mature soils the important variables included in the final soil-factor equation for predicting site index are (1) percent of clay in the B_2 horizon, (2) percent of fine sand in that horizon, (3) the difference in silt-plus-clay contents between the B_2 and A horizons, and (4) the thickness of the B_2 horizon. Average depth to free water and fluctuations in this depth during the growing season are important water-table variables, especially in recent alluvial deposits.

Soil series are of value in site prediction, largely because subsoil textures are important both in soil classification and in their effect on the growth of sweetgum. The value of soil series in site prediction could be increased by mapping the relative thickness of subsoils (B_2 horizons), and by putting more emphasis on fine-sand content as opposed to total sand.

The results reported here are applicable only to the New Jersey Coastal Plain, and even there should be applied only to wet soils or to moderately well-drained soils of intermediate texture. Present plans are to extend this study to include Delaware and Maryland. It is expected that the additional data will improve both the sampling of soil series and the accuracy of regression estimates.

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■

Appendix

I

DESCRIPTION OF SOILS MOST FREQUENTLY SAMPLED

Adelphia loam

A horizon: 12 to 14 inches of dark grayish-brown, granular loam.

B horizon: olive-gray to yellowish-brown, somewhat blocky, sandy-clay loam, containing a moderate amount of glauconite.

C horizon: olive or olive-gray glauconitic parent material; more sandy and permeable than B horizon.

Distinct or prominent mottling below the brownish surface soil indicates moderately good to somewhat poor drainage. Water level[2] was at 12 to 24 inches between September and April, at 36 to 60 inches in July and August.

Bayboro loam

A horizon: 10 to 14 inches of black or very dark gray, granular loam.

B horizon: 10 to 16 inches of prominently mottled, gray, blocky clay or clay loam that is firm and plastic.

C horizon: prominently mottled, yellowish-brown or grayish-brown clay or clay loam.

Dark surface soil over a gray subsoil indicates very poor drainage.

Water level at an average depth of 6 inches between September and April; at 18 to 60 inches in July and August.

Bustleton loam (local name not correlated with national system)

A horizon: 6 to 10 inches of dark gray, granular loam.

B horizon: 10 to 30 inches of prominently mottled, yellowish-brown, blocky loam or clay loam that is firm and plastic.

C horizon: stratified; fine-sandy loam to clay layers; in places containing cemented ironstone.

Prominently mottled yellowish-brown subsoil and gray surface soil indicate poor drainage. Water level at 6 to 18 inches from September to April; at 30 to 60 inches in July and August.

Keansburg fine-sandy loam

A horizon: 6 to 14 inches of black or very dark gray, granular, fine-sandy loam.

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[2] Water levels based on periodic measurements during 1 year at wells installed on the plots. Water levels mentioned are approximate averages for the periods and plots sampled.

B horizon: 12 to 18 inches of prominently mottled, gray to olive gray, somewhat blocky sandy loam.

C horizon: containing some glauconite, but sandier than B horizon.

Prominently mottled gray subsoil and dark surface soil indicate very poor drainage. Water level at 2 to 12 inches from September to April; 12 to 40 inches in July and August.

Matlock loam

A horizon: 12 to 16 inches of black or very dark gray, granular loam.

B horizon: 14 to 18 inches of prominently mottled, olive, blocky, sandy clay that is firm and plastic.

C horizon: sandier and more permeable than B horizon.

Although very poorly drained, these soils are not gray beneath the dark surface because the B and C horizons are highly glauconitic (olive colored). Water level at 2 inches from September to April; at 6 to 60 inches in July and August.

Othello loam

A horizon: 7 to 14 inches of dark gray, mottled, granular loam.

B horizon: 18 to 24 inches of prominently mottled, very dark gray, somewhat blocky loam or silt loam that is firm and plastic.

C horizon: sandier than B horizon; generally stratified, in places with gravel.

Gray surface over gray subsoil indicates poor drainage.

Rancocas fine-sandy loam (local name not correlated with national system)

A horizon: 6 to 10 inches of black to very dark brown, granular, fine-sandy loam.

B horizon: 16 to 26 inches of prominently mottled, dark gray or very dark gray, somewhat blocky to blocky, loam to clay loam that ranges from friable to firm and plastic.

C horizon: stratified, granular layers of fine sand to sandy clay, mostly olive colored.

Soils are considered very poorly drained. Water level at 6 inches from September to April; at 30 to 40 inches in July and August.

Weeksville fine-sandy loam

A horizon: 14 to 16 inches of black or very dark gray, granular, fine-sandy loam.

B horizon: prominently mottled, gray or grayish-brown, somewhat blocky, friable, fine-sandy loam.

C horizon: usually below 40 inches; a friable, gray, loamy fine sand. Sand is predominantly and uniformly fine.

Drainage considered to be very poor; water level at 2 inches from September to April, and at 36 to 48 inches in July and August.

II

DATA FROM SOIL-TEXTURE ANALYSES

To supplement the above soil descriptions, average data from the texture analyses of each soil series are given below (table 3). The usual sampling methods are described in the text. However, it should be noted here that in recent alluvial deposits samples of the B_2 horizon were arbitrarily taken from the 10- to 20-inch depth.

Table 3. — *Average data for soil series, from texture analysis*

Soil series	Silt-plus-clay content of A horizon	B_2 horizon		
		Fine-sand content	Silt content	Clay content
	Percent	*Percent*	*Percent*	*Percent*
Klej	11	41	7	4
Rutlege	9	25	6	3
Nixonton	20	42	5	21
Dragston	15	18	11	9
Fallsington	16	23	21	10
Pasquotank	14	49	5	10
Keansburg	26	48	16	22
Weeksville	28	51	15	22
Pocomoke	12	24	16	10
Collington	10	35	2	21
Mattapex	45	31	22	23
Adelphia	42	31	22	27
Bustleton	55	33	33	24
Othello	53	27	37	25
Rancocas	41	33	23	29
Bayboro	38	30	17	35
Colemantown	58	21	15	52
Matlock	31	22	10	37
Glauconitic alluvium	22	53	13	15
Non-glauconitic alluvium	14	26	7	8

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Relationships between

Visitor Characteristics and Recreation Activities

on two National Forest areas

by J. Alan Wagar

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1963

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RALPH W. MARQUIS, DIRECTOR

The Author—

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Relationships between

Visitor Characteristics and Recreation Activities

on two National Forest areas

NEARLY every discussion of problems in outdoor recreation emphasizes the need of planners and administrators to know more about the people who seek recreation: their desires, their attitudes, and the kind of activities they prefer as well as what segments of the population they represent. Thus, as a preliminary study in recreation research, the Northeastern Forest Experiment Station sought to determine the relationships between the characteristics of visitors and their interests in recreational use of forest land. The study was also designed to guide future research in recreation.

A questionnaire was used on two National Forest recreation areas to establish these relationships and to determine: (1) what

Figure 1. — A typical summer scene at Twin Lakes Recreation Area, near Kane, Pa., one of the two areas where a study was made to determine what people want of a recreation area.

types of people were using these areas, (2) what these visitors were doing, (3) what they wanted, and (4) how much they enjoyed their visits.

The study was conducted at the Stuart Recreation Area on the Monongahela National Forest in West Virginia and at the Twin Lakes Recreation Area on the Allegheny National Forest in northwestern Pennsylvania (fig. 1 and fig. 2). Each of these areas is located in a pleasant forest environment near a small town; each offers swimming, picnicking, and camping. The Stuart Recreation Area, operated by Forest Service personnel, charges no admission

fee. The Twin Lakes Recreation Area, on the other hand, is operated by a concessionaire who charges for admission.

The sample does not represent a full cross-section of outdoor recreationists because the study was limited to visitors attracted by the specific offerings of these two recreation areas. Also, because response was voluntary, the returned questionnaires may not accurately represent the attitudes of all visitors. Thus the results offer no guaranteed planning formulas but simply present information that can be combined with knowledge from other sources to guide planners, administrators, and researchers. In addition, this study illustrates a method of analyzing research data and presenting relationships.

Figure 2. — A family picnic group at Twin Lakes. Picnicking ranked high among activities at both areas.

Procedures

At each recreation area, questionnaires were offered to a systematically selected sample of visitors over 15 years old. Approximately 950 visitors were invited to take questionnaires and to fill them out while on the area and return them either in person or by mail. To facilitate the return of questionnaires, a self-addressed, postpaid envelope was attached to each one. Only about 10 people refused to accept questionnaires.

As one test of differences between respondents and nonrespondents, the sex and estimated age of each person given a questionnaire were recorded. At both recreation areas the rate of response from visitors estimated to be between 20 and 39 years old was lower than for visitors who were estimated to be either younger or older than this group. This difference was statistically significant (at the 95-percent level of confidence) at the Stuart Recreation Area but not at Twin Lakes.

Approximately half of the respondents at the Stuart area and two-thirds of the respondents at Twin Lakes returned questionnaires in person before leaving the area. The rest of the respondents returned questionnaires by mail.

At the Stuart area, 527 questionnaires were distributed during 5 days (3 weekdays and 2 weekend days) in late August 1960. Of these, 299 (56.7 percent) were returned. At Twin Lakes, 416 questionnaires were distributed during 9 days (5 weekdays and 4 weekend days) in late July and early August 1960, and 279 (67.1 percent) were returned. Only four of these were unusable, and these were all from young visitors who obviously falsified their answers.

Answers to each questionnaire were coded and put on a punch card. Cards were then machine-sorted, and responses were tabulated for each question (table 1, Appendix). Of more importance, sorting provided cross-tabulations that could be tested to determine whether responses to one question were related to responses to other questions. Relationships between responses were tested for statistical significance by Chi-square. (An example is given in the Appendix). The results reported here include only those relation-

ships that showed at least a 95-percent probability that they really existed and were not just chance combinations of data.

Participation of specific groups of people in various activities has been expressed in percentages to identify recreation habits. However, the group with the highest rate of participation may not contribute the greatest number of participants. For example, the greatest *number* of picnickers on the Stuart Recreation Area lived within 10 miles. But there was a higher *percentage* of picnickers among respondents from the 11- to 30-mile zone.

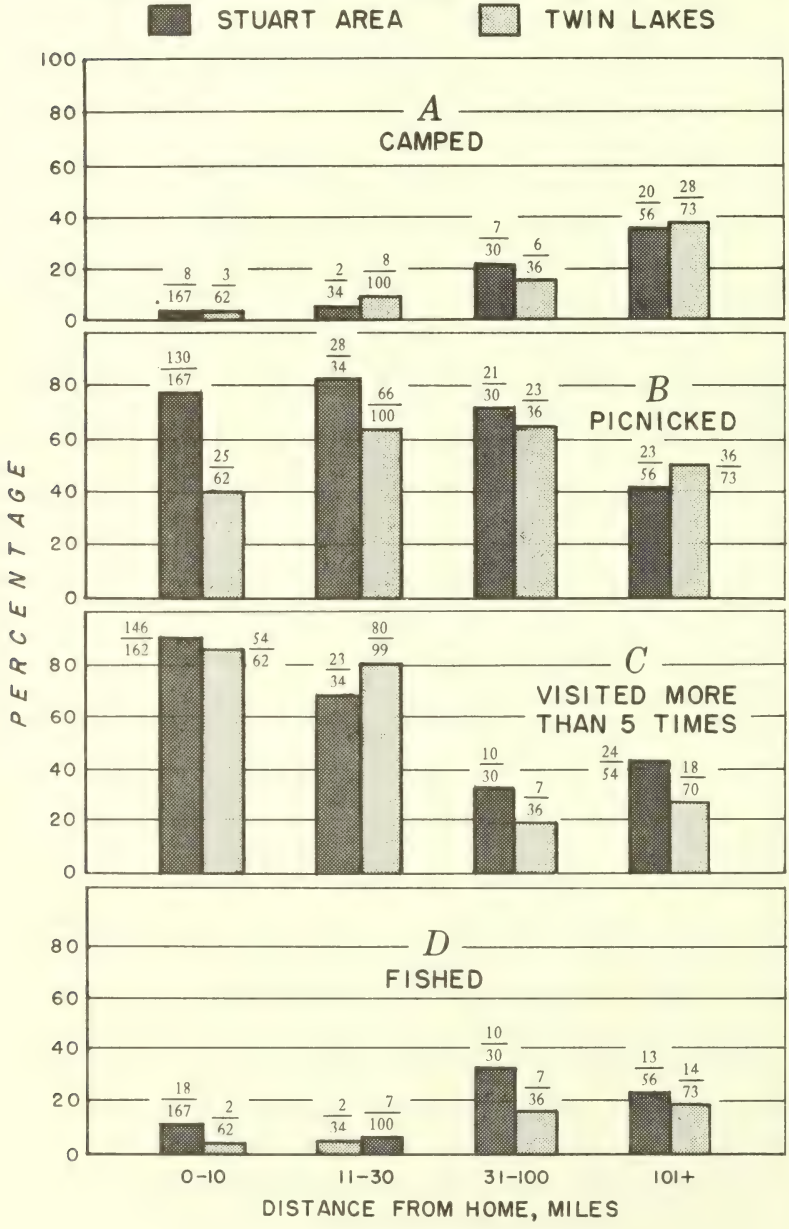
In this type of study it is always possible that the people who did not answer are different in their recreational preferences from the people who did. However, it was not possible to follow up the people who did not respond; and results refer only to the people who returned questionnaires. Because of the statistical procedures used to analyze the data, we can be at least 95 percent sure that the following relationships existed among the visitors who did reply.

Results

Answers from visitors to the Twin Lakes and Stuart Recreation Areas were sufficiently different so that some characteristics, attitudes, and actions of visitors to the one area could not be adequately predicted from a survey on the other area. Thus when responses from Twin Lakes were compared with responses from the Stuart area, significant differences were found in distributions of age, income, education, marital status, distance from home, reasons for visiting, number of previous visits, hours spent per visit, and the proportion of respondents who picnicked, swam, sat and watched, or pursued some active recreation.

In spite of the many differences between visitors to the Stuart area and Twin Lakes, several relationships between visitor characteristics and activities were similar on both areas. Although a sample of only two areas does not permit generalization, the similarity of results suggests that some of these relationships may have wide application and should be tested by further research.

Figure 3. — Recreation activities at the two areas, as related to the distance visitors traveled to get there. In this and the following charts the fractions over the bars show the data used to compute percentages. For example, in the top graph, 8/167 over the first bar indicates that, among the 167 respondents within 10 miles of home, 8 were camping.



In the following presentation, relationships common to both areas are separated from patterns found on only one area.

Relationships Common To Both Areas

Participation in several activities was related to the distances people lived from the recreation areas. The percentages of respondents who camped increased with distance from home (fig. 3,A). On each area the percentage of respondents who picnicked was highest for the 11- to 30-mile zone and decreased for greater distances (fig. 3,B). The lower percentage of picnickers from the 0- to 10-mile zone can undoubtedly be explained by the ease with which nearby residents could visit for part of a day and return home for meals.

As would be expected, the respondents living closest to the area visited it most frequently (fig. 3,C). The percentage of frequent visitors decreased with distances out to 100 miles but then increased again. This increase probably resulted from the popularity of the areas with campers, the majority of whom arrived from distances greater than 100 miles. At both areas, fishing was more popular among people who lived more than 30 miles away than among visitors who lived closer (fig. 3,D).

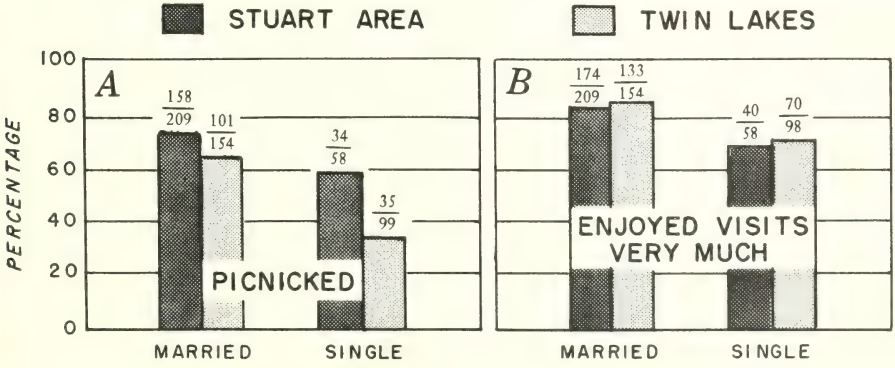


Figure 4. — Marital status as related to the visitors who picnicked, and to those who said they enjoyed their visits very much.

Married visitors were more likely than single people to picnic (fig. 4,A) and to say that they enjoyed their visits very much (fig. 4,B). Higher percentages of married respondents arrived with family (fig. 5,A) and higher percentages of single respondents arrived alone (fig. 5,B) or with friends (fig. 5,C). Only male respondents indicated that they arrived alone. And of all male respondents, only 5.2 percent arrived alone at the Stuart area and 7.8 percent at Twin Lakes.

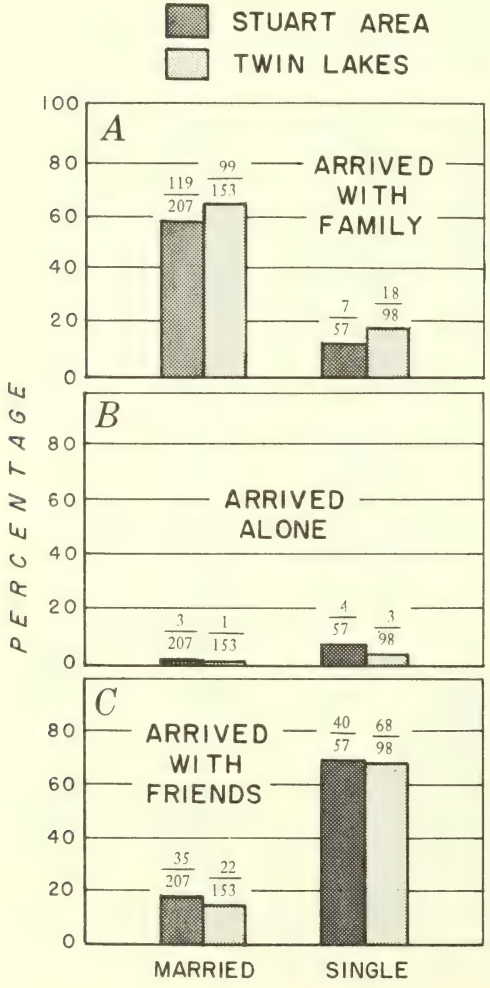


Figure 5.—Marital status as related to the groupings in which visitors arrived.

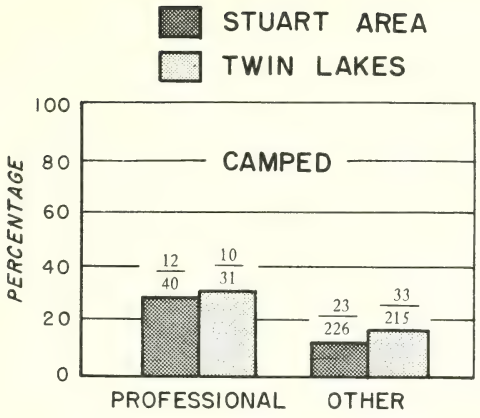


Figure 6. — Recreational activities were related to type of employment. Professional people were more likely to camp than others.

Significantly higher proportions of professional people camped at both areas than did respondents with other occupational classifications (fig. 6). Housewives and other non-income-producers were classified according to the occupation from which their family incomes were primarily derived.

Stuart Recreation Area

The percentage of people who were sightseeing at the Stuart Recreation Area tended to increase with their distance from home and was greatest for the 31- to 100-mile zone (fig. 7). Visitors seeking new sights probably travel farther than visitors with other motivations. Also, people are apt to become increasingly curious

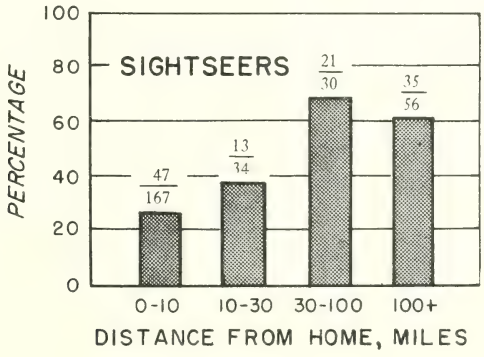
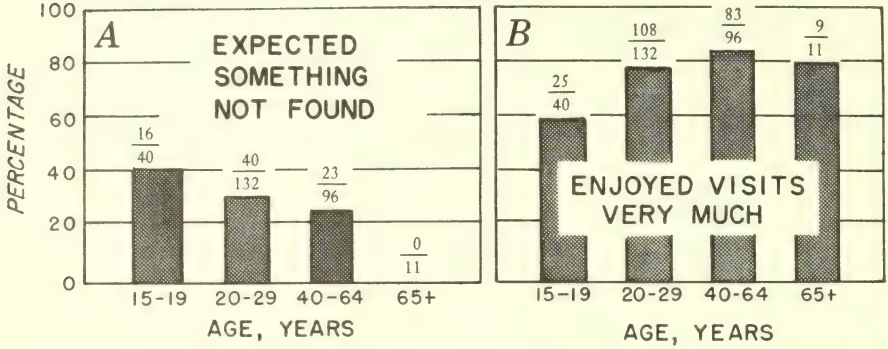


Figure 7.—Stuart Recreation Area: distance from home as related to sightseeing.

Figure 8. — Stuart Recreation Area: relationships among age groups and enjoyment of the area. Younger people seemed to be less satisfied than older people.



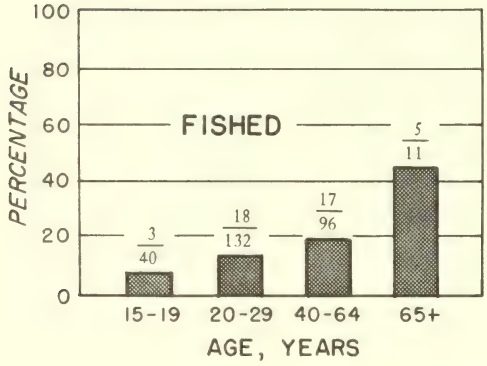


Figure 9. — Stuart Recreation Area: relationship between age and fishing.

about their surroundings when they leave their everyday environments. The slight decrease in sightseeing by visitors from more than 100 miles away may have resulted from the fact that campers predominated in this group. Thus camping might have replaced curiosity and sightseeing as the prime factor motivating travel for some visitors from this distance zone.

The percentage of respondents who expected something not found on the Stuart Recreation Area decreased with age (fig. 8,A) and fewer teenagers replied that they enjoyed their visits "very much" than did older respondents (fig. 8,B). These results indicated a tendency for young people to be less satisfied than older

people with their visits to the area. The explanation for this difference between age groups may be important in planning for future recreational developments, and further research is needed to determine what this difference means.

The percentage of visitors who fished increased with age (fig. 9). Fishing was more popular among men than women. Sitting and watching were more popular among women.

As income increased, the percentage of people who were camping increased (fig. 10,A). However, in actual numbers more than

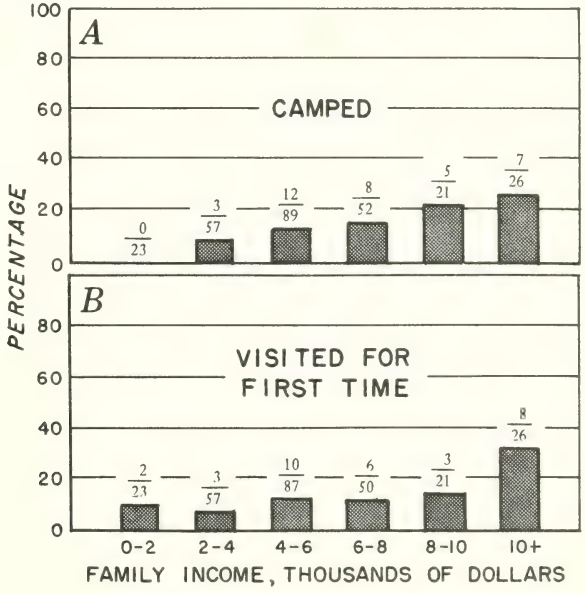


Figure 10. — Stuart Recreation Area: family income related to recreation activities.

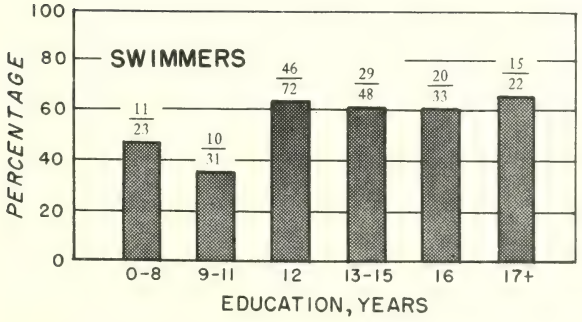


Figure 11. — Stuart Recreation Area: education related to swimming.

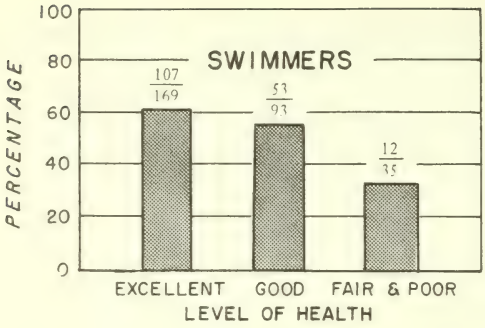


Figure 12.—Stuart Recreation Area: swimming related to health.

half of the campers sampled had incomes between $4,000 and $8,000. The percentage of visitors making their first visit to Stuart tended to increase with income (fig. 10,B)—probably indicating that people with the higher incomes travel more widely than people with lower incomes.

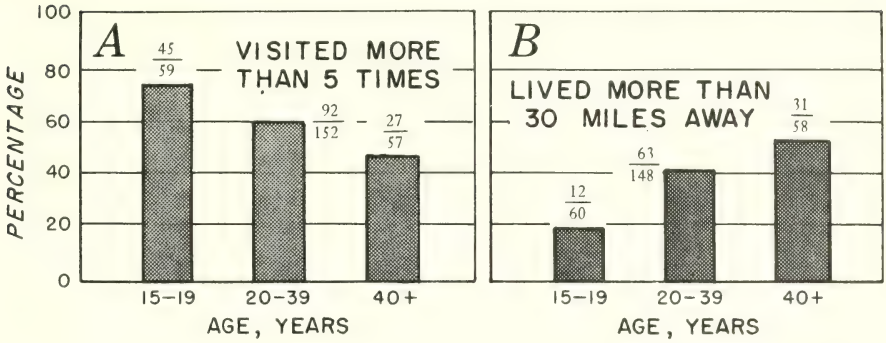
Adult visitors to the Stuart area who did not complete high school were less likely to swim than were adults with more education (fig. 11). This difference may indicate that people who are able to go to school longer also have greater opportunity to develop recreational skills. As might be expected, fewer people with poor or fair health swam than did visitors who indicated good or excellent health (fig. 12).

Twin Lakes Recreation Area

Young people visited Twin Lakes more frequently than older people (fig. 13,A). Women visited the area more frequently than men. The percentage of visitors who lived more than 30 miles away increased with age (fig. 13,B)—indicating that older people may travel more widely than others. (This trend would probably reverse beyond retirement age, but the sample at Twin Lakes included very few visitors over 64).

At Twin Lakes, a higher percentage of married than single people came from more than 30 miles away; a higher percentage of married people were found to be camping; and a higher percentage of single people came for the purpose of sightseeing or were found to be sitting and watching. Finally, a smaller percent-

Figure 13. — Twin Lakes Recreation Area: relationships between age, frequency of visits, and distance traveled.



age of visitors in the below-$2,000 income class participated in active recreations at Twin Lakes than did people with higher incomes. One explanation may be that the lowest income group included retired people and working women.

Conclusion

The results of this study tell us much about visitors on the Stuart and Twin Lakes Recreation Areas. Although these results cannot now be applied directly to other areas with any assurance, the fact that some relationships are nearly identical on both areas may indicate widespread uniformity in visitor use-patterns. And if additional studies show further uniformity it should be possible to accurately project some visitor use-patterns from the trends found in population, education, leisure, and the economy.

■

Appendix

I

Table 1. — *Responses to the questions asked in recreation study*

Item	Stuart Area[1]	Twin Lakes[1]
	Percent	*Percent*
What was your most important reason for coming to this recreation area?		
Swimming and sunning	20.1	39.8
Preference for specific traits of area	11.7	16.5
Picnicking	30.4	9.7
General enjoyment	7.0	9.3
Interest in opposite sex	1.0	2.9
Scenery or sightseeing	4.3	1.4
Part of other or longer trip	4.3	1.4
All other answers	18.8	17.9
No response	2.4	1.1
While you are here, what things are you doing?[2]		
Fishing	14.7	10.8
Sightseeing	39.8	35.5
Camping	[3]13.4	[3]16.1
Sitting and watching	53.5	73.5
Picnicking	70.6	55.2
Swimming	57.9	83.5
Hiking	25.4	19.0
Other	[4]17.1	5.0
Proportion of respondents who participated in some form of active recreation (fishing, swimming, hiking)	69.2	85.7
How much are you enjoying your visit here?		
Very much	80.2	79.6
Fairly well	18.1	20.1
Not very much	1.0	.0
Not at all	.7	.0
No response	.0	.3

[1] Unless otherwise indicated, percentages for the Stuart area are based on 299 questionnaires and those for the Twin Lakes area are based on 279 questionnaires.

[2] Because more than one answer could be checked, answers to this question total more than 100 percent.

[3] The indicated percentage of campers at both areas may be affected by sampling procedures and therefore could be nonrepresentative.

[4] Answers most commonly listed under "other" by visitors to the Stuart area were: Softball, vesper services, visiting, horseshoes, cards, and other games.

CONTINUED

Table 1. — *(continued)*

Item	Stuart Area[1]	Twin Lakes[1]
	Percent	*Percent*
Is there a state park or forest recreation area closer to your home than this?		
Yes	[5]25.8	[6]60.9
No	69.2	36.9
Don't know	3.3	1.1
No response	1.7	1.1
How many times have you been here?		
First time	11.7	20.1
2 to 5 times	15.7	19.3
6 or more times	69.9	59.5
No response	2.7	1.1
How much time do you usually spend here?		
Day visitors:[7]		
1 to 2 hours	20.1	9.4
3 to 4 hours	44.0	44.8
5 or more hours	26.2	39.0
No response	9.7	6.8
Overnight visitors:[8]		
1 to 2½ days	35.0	22.2
3 to 5½ days	27.5	26.7
6 to 16½ days	17.5	28.9
17 to 30½ days	.0	.0
31 or more days	2.5	6.7
No response	17.5	15.5
Are you?		
Male	44.8	41.9
Female	41.8	45.5
No response	13.4	12.6
Are you?		
Married	69.9	55.2
Single	19.4	35.5
No response	10.7	9.3

[5] Audra State Park, near Audra, W. Va., was the closer park area most commonly mentioned.

[6] Bendigo State Park, near Johnsonburg, Pa., was the closer park area most commonly mentioned.

[7] Percentages based on 259 questionnaires from the Stuart area and 234 questionnaires from Twin Lakes.

[8] Percentages based on 40 questionnaires from the Stuart area and 45 questionnaires from Twin Lakes.

CONTINUED

Table 1. — *(continued)*

Item	Stuart Area[1]	Twin Lakes[1]
	Percent	*Percent*
Which age group are you in?		
15 to 19	13.4	21.5
20 to 39	44.1	55.2
40 to 64	32.1	20.4
65 plus	3.7	.7
No response	6.7	2.2
Do you consider your health—		
Excellent	56.5	64.5
Good	31.1	28.7
Fair	10.4	5.4
Poor	1.3	.0
No response	.7	1.4
About what is the annual income of your family before taxes?[9]		
$0 to 1,999	7.7	3.9
$2,000 to 3,999	19.0	14.7
$4,000 to 5,999	29.8	38.7
$6,000 to 7,999	17.4	12.9
$8,000 to 9,999	7.0	9.0
$10,000 plus	8.7	7.5
No response	10.4	13.3
How many years of school have you completed?[10]		
Primary schooling only	9.6	4.7
High school started, not completed	13.0	13.7
High-school graduate	30.1	42.4
College started, not completed	20.1	18.9
College graduate	13.8	13.7
Post-graduate study	9.2	4.2
No response	4.2	2.4

[9] Income data are probably inaccurate, especially in the $10,000 plus bracket. Many respondents either did not answer this question or else checked several answers. A few respondents wrote "none of your business" or similar comments on the questionnaire. The age, education, and occupation given by some respondents did not support the high income figures they checked.

[10] Responses from visitors younger than 20 are not included. Percentages are based on 239 questionnaires from the Stuart area, 212 from Twin Lakes.

CONTINUED

Table 1. — *(continued)*

Item	Stuart Area[1]	Twin Lakes[1]
	Percent	*Percent*
What occupation provides the main source of income for your family?		
"Blue collar"	21.8	34.4
Professional	13.4	11.1
Business and sales	11.7	9.3
Other white collar	3.3	5.4
Unemployed	.0	1.1
Retired[11]	.7	.4
Other[12]	38.1	26.5
No response	11.0	11.8
Did you come to this area—		
Alone	2.3	1.4
With family	47.8	48.4
With friends	27.8	33.7
With family and friends	21.4	15.8
No response	.7	.7
How far away do you live?		
0 to 10 miles	55.9	22.2
11 to 30 miles	11.4	35.8
31 to 60 miles	7.7	12.2
61 to 100 miles	2.3	.7
100 miles or more	18.7	26.2
No response	4.0	2.9

[11] Former occupations of retired people were coded if possible.

[12] Many of the answers given as occupation were not specific enough to code, hence the large percentages of "other" occupations.

II

Example of Chi-Square Analysis

Punch cards for the Stuart Recreation Area were sorted according to the distances respondents lived from the area. The cards for each distance zone were then further sorted into two groups: *camped* and *didn't camp*. Counts of the sorted cards provided observed values for the cells of the following tabulation:

	Distance from home, in miles				
	0-10	*11-30*	*31-100*	*101+*	*Total*
Camped:					
Observed	8.	2.	7.	20.	37
Expected	21.53	4.38	3.87	7.22	—
Difference	13.53	2.38	3.13	12.78	—
Didn't camp:					
Observed	159.	32.	23.	36.	250
Expected	145.46	29.61	26.13	48.78	—
Difference	13.54	2.39	3.13	12.78	—
Totals	167.	34.	30.	56.	287

Expected values for each cell were computed by proportioning the marginal totals in each distance zone according to the proportions of the grand total made up of campers and non-campers. Thus the expected value for campers in the 0-10 zone equals $167 \times (37/287) = 21.53$; the expected value for non-campers in the 0-10 zones is $167 \times (250/287) = 145.46$; etc. The values obtained by squaring each difference and dividing it by the expected value were then summed to give the computed value of Chi-square. This equals $(13.53)^2/21.53 + (2.38)^2/4.38 + (3.13)^2/3.87 + (12.78)^2/7.22 + (13.54)^2/145.46 + (2.39)^2/29.61 + (3.13)^2/26.13 + (12.78)^2/48.78$, which equals 40.10 at 3 degrees of freedom. Degrees of freedom equal the number of columns minus one (in this case $4 - 1 = 3$), times the number of rows minus one (in this case $2 - 1 = 1$). A table of Chi-square values shows that a value of 40.10 could be explained by chance less than 1 time in 1,000. Therefore we can reject the hypothesis that participation in camping is independent of distance from home.

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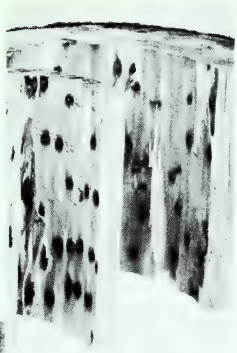
Alex L. Shigo



Ring Shake associated with Sapsucker Injury

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FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
RALPH W. MARQUIS, DIRECTOR

Ring Shake associated with Sapsucker injury

The Author—

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Figure 1. — The yellow-bellied sapsucker; adult male on the left and a young bird at right. From *The Birds of Minnesota,* vol. 1, by Thomas S. Roberts. The University of Minnesota Press, Minneapolis. Copyright 1932 by the University of Minnesota.

The Sapsucker

THE three species of woodpeckers properly classed as sapsuckers have been called the evildoers of the woodpecker tribe (Roberts 1932). These three birds differ in several ways from the 20 or so other woodpecker species found in the United States. Though their chief insect food is ants, a large part of their diet consists of the cambium and inner bark of trees, and they drink a great deal of tree sap (Beal and McAtee 1922).

These sapsuckers sample the sap and cambium of many trees around their nesting sites, and select the particular trees that appeal to them for future tapping. The selected trees become the birds' orchard, and the birds tap them repeatedly until many are badly injured, and some are killed. Sapsuckers are known to attack

more than 258 species of woody plants, and defects due to sapsucker attack have been found in the wood of 174 tree species (Beal and McAtee 1922).

The type of damage that sapsuckers do has been known for a long time, especially by people concerned with fruit orchards and ornamentals (Roberts 1932). However, sapsucker damage has not been a matter of much concern for foresters. This is partly because most of the injuries are on hemlock, a low-value species; and damage on hardwoods is high on the stem, where it is difficult to notice in a dense forest. Recently, though, Ziller and Stirling (1961) pointed out the damage done by the western species of this bird—the red-breasted sapsucker—in coastal British Columbia. Here these sapsuckers caused considerable damage to mature hemlock (*Tsuga heterophylla* (Raf.) Sarg.) by inflicting many small wounds at the base of the tree.

In the Northeast the common species of sapsucker is *Sphyrapicus varius varius* L., the yellow-bellied sapsucker (fig. 1). Some recent observations indicate that there is a direct association between sapsucker injury and the separation of the wood at the growth rings —commonly called ring shake—in living softwood and hardwood trees.

Observations

The observations of sapsucker damage were made since 1959 in the Saco River district of the White Mountain National Forest in New Hampshire. Sapsucker injuries were observed on the following tree species: eastern hemlock (*Tsuga canadensis*), paper birch (*Betula papyrifera*), yellow birch (*Betula alleghaniensis*), sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), and beech (*Fagus grandifolia*).

In the field observations it was noted that the birds concentrated on certain trees in each area, but did not touch other trees nearby. On the attacked trees, the bark was completely killed on some parts of the stem; and older healed areas had the appearance of old scrape wounds (fig. 2).

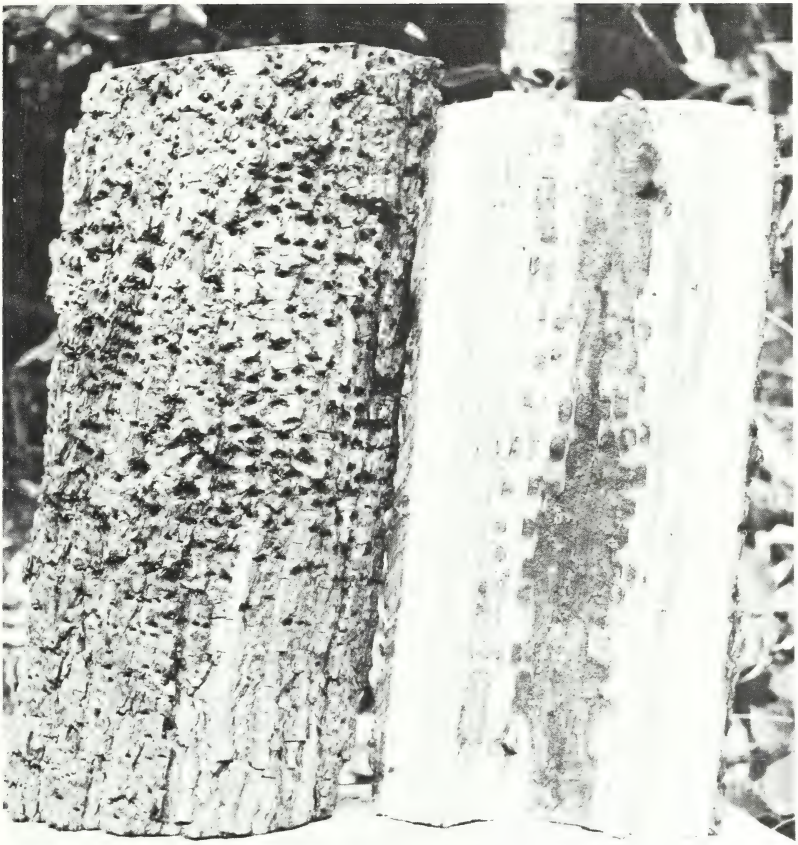

Figure 2. — Two sections of a hemlock tree, showing sapsucker wounds. Left, the bark is pocked with sapsucker wounds, and the smooth patch of bark shows where concentrated wounds killed the bark 40 years ago. Right, inside the tree a ring-shaken piece was pulled off, exposing a large dark 40-year-old wound and a number of small wounds.

The sapsucker injuries were first examined on trees that had been cut for studies of decay. (The fungi associated with the discolorations around the injuries were isolated from samples collected in the field. A few noteworthy fungi isolated were *Verticillium* sp., *Ceratocystis* sp., *Graphium* sp., and *Daldinia concentrica.*)

The importance of the sapsucker damage was not fully realized until hemlock trees were dissected and examined. Two interesting

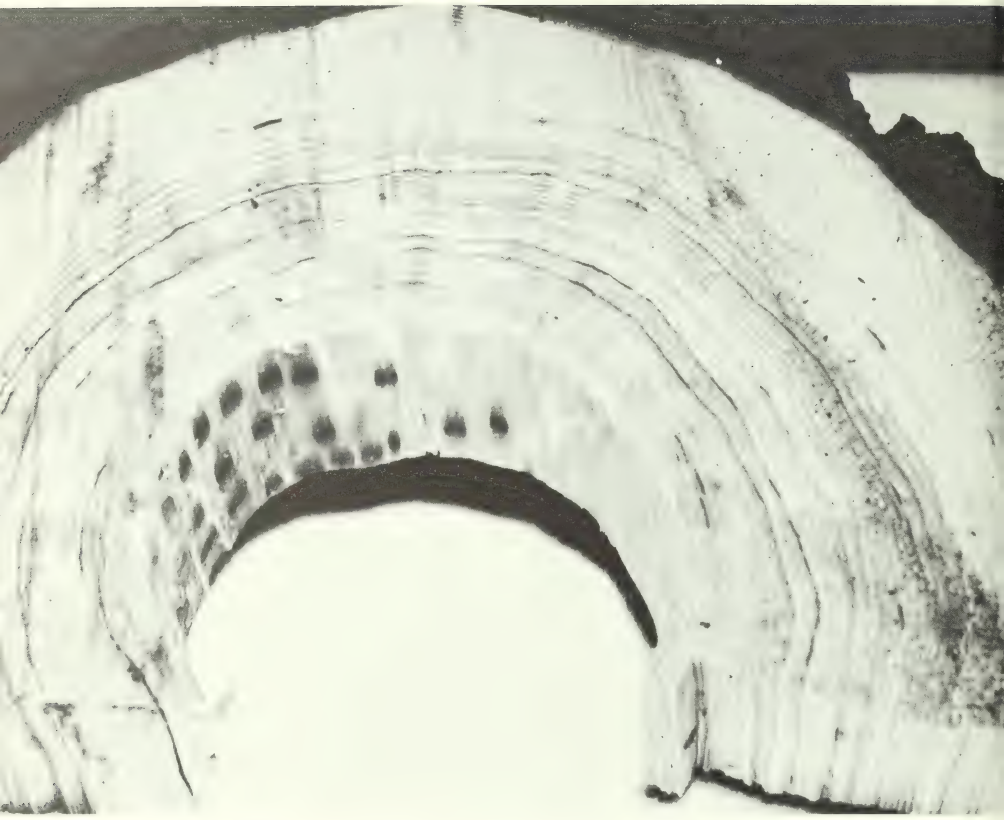

Figure 3. — A sample section from a hemlock stem, showing the dark lines along the growth rings, and 75-year-old sapsucker wounds on the surface exposed by pulling out the ring-shaken core.

defects in the wood were noted. Cracks between the growth rings —ring shakes—were abundant near the lower part of the trees. And heavy dark lines were found between some annual rings higher up the stem (fig. 3).

Many tree sections having shake, and those having the dark annual rings, were pulled apart and examined (figs. 2, 3, and 4). The sections from the lower parts of the stem usually separated easiest. Many small scars were seen on the inside surfaces of the separated sections. The smooth hemlock wood was pink to yellow when first separated, and the dark red scars formed a striking

pattern on this background. The pattern was disrupted only where the wood had been so badly scarred that callus tissue was present, and in some areas where decay had obliterated most of the old scars (fig. 2).

To verify these observations, 25 trees on different sites that had old but discernible sapsucker wounds in the bark were dissected and examined. All had internal sapsucker scars, and the wood separated at these injured places. The holes could still be seen in the bark (fig. 2) more than 60 years after the injuries had been made. The holes in the bark matched with scars on the wood 40 and 60 years inside the stem. In one hemlock 18 inches in diameter breast high, sapsucker scars were found on the growth ring that had formed when the tree was 2 inches d.b.h.

The ease of separation of the wood at the growth rings depends on the time since the wounds were inflicted, the concentration of

Figure 4. — This hemlock sample pulled apart along several ring-shake cracks. Sapsucker wounds line the surfaces of the separated sections.

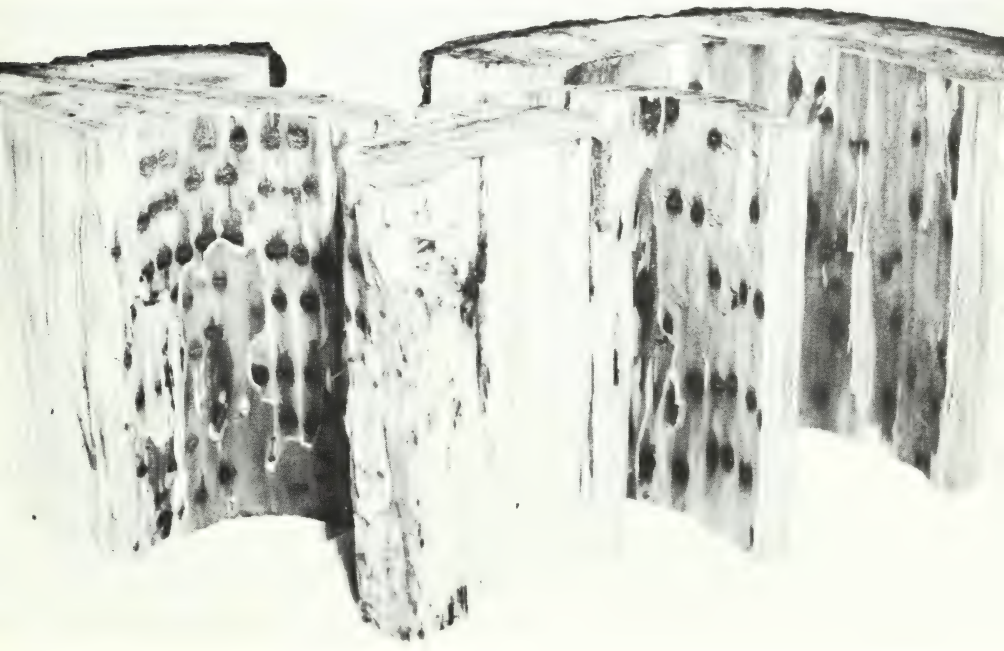

Figure 5. — The sapsucker attacks some hardwoods, too. This separated ring-shake sample from a paper birch bears old sapsucker wounds. The separation was evident several inches above and below the wound.

wounds in any one area on the tree, and whether decay fungi have invaded these areas.

An examination of hardwoods injured by sapsuckers revealed that the pattern of the internal scars was similar to those found in hemlock (fig. 5). The ring shakes found in the hardwoods were limited to a few inches above and below the old injuries. And the areas injured on hardwoods were much smaller than those on hemlock.

Repeated sapsucker tappings in one area on the bark of hardwoods was not common. Usually the birds girdled a section, which resulted in the death of the portion above (fig. 6); or the concentrated wounds killed portions of the stem, resulting in one large wound (fig. 7). It was hard to realize that sapsuckers caused the open smooth wounds frequently found in the crowns of trees, but

Figure 6. — The top of this paper birch was killed by girdling sapsucker wounds.

Figure 7. — Sapsucker wounds on red maple. On the section at right, old dead strips of bark still cover the lower wounds. Similar strips of dead bark can be seen around the large wound on the section at left.

several of these wounds were found that still had some of the old dead bark covering them (fig. 7).

Ring shake was found in paper birch trees where the sapsucker wounds went around the stem, but did not completely girdle it (fig. 5). These old injured areas appeared as black swollen bands around the trees, and were usually near the base of the crown.

Discussion

Many different explanations for ring shake have been presented (Wilson 1962), but none have been widely accepted. Growth stresses and compression failures have been pointed out as possible causes (Koehler 1933). Mergen (1958) states that shakes are the results of rupturing between the cells, and occur either along the boundary of two rings, or within the cells of the ring itself.

The concentrated small injuries made by the sapsuckers could easily weaken the fibers along the newly-formed ring of wood, and these weakened areas may not separate until certain stresses that accompany aging of the wood begin. If obesrvations are made only on well-separated sections of wood near the center of old trees, the sapsucker scars would probably not be noticed because of the obliteration of these small scars by decay and the natural fading of the small wounds. The work of the sapsucker would also be missed, especially in hemlock, if old shakes were examined and the sapsucker injuries were located at a slightly different area, above or below the place examined. Also, concentrated wounds that kill the bark in one area usually leave few small individual scars in the wood, and in this case too it would be difficult to realize that a bird had caused the large wound.

The mature eastern hemlock trees cut in logging operations in the White Mountains are usually more than 18 inches d.b.h. and fairly old. As these trees get older, the bark thickens and the birds find the trees less appealing. At the same time it becomes progressively more difficult to notice the old sapsucker wounds in the bark. When these trees are finally cut, it is almost impossible to associate the old sapsucker injuries with the ring shake. Therefore, to observe the shakes associated with sapsucker injuries, trees must be dissected and examined that still have an abundance of discernible sapsucker wounds on the bark, and the trees should be at least 100 years old.

In the observations reported in this paper, ring shake was found consistently where concentrated sapsucker wounds were inflicted at least 75 years ago. A more intensive investigation is necessary for an understanding of the full impact of sapsucker damage.

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CONDITIONING
Loblolly Pine Stands in Eastern Maryland
FOR REGENERATION

by S. Little and J. J. Mohr

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CONDITIONING
Loblolly Pine Stands in Eastern Maryland
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THE RESULTS of this experiment provide a strong case for site conditioning in advance of harvest cuttings. Conditioning treatments are highly desirable from both silvicultural and economic considerations. Foresters who manage industrial holdings in this area should give serious thought to providing such treatments. State foresters working with private owners should direct their recommendations and programs toward this end.

—H. C. BUCKINGHAM
State Forester
Department of Forests and Parks
Annapolis, Md.

On Maryland's Eastern Shore, loblolly pine stands are commonly the most profitable type of forest. The climax hardwoods here are of relatively low value on most sites. Other conifers occur here: pond pine and its gradations to loblolly are common associates in certain sections, and Virginia and shortleaf pines are found on the drier sites. However, because loblolly generally grows faster than the other pines, it ranks as the most desirable species.

Many of today's best loblolly stands originated on old-field sites, the pines having seeded in when cultivation ceased. Unfortunately hardwoods also invade these areas, but usually somewhat more slowly than the pines, so that they form dense understories by the time the pines are mature. When the pine stands are logged, these hardwoods tend to take over much of the growing space. Heavy logging may damage or uproot many of the hardwoods, but logging alone does not set them back enough to enable relatively pure stands of pine to become established for the next crop.

Figure 1.—Original stand conditions in the study area before conditioning treatments.

Certain supplemental measures do provide the desired pine stands—if applied just before seedfall in years of heavy seed crops. In one study, for example, a hot slash burn in early September after a seed-tree cutting permitted loblolly pine to form a relatively pure stand, whereas in adjacent unburned plots the pines gained dominance only in spots that were much disturbed during logging. However, such a summer burn can be applied effectively only under suitable weather conditions in years with good seed crops (3, 5).

Measures that would be effective in both good and bad seed years were needed. So in 1952 the Northeastern Forest Experiment Station and the Maryland Department of Forests and Parks started tests of other treatments for reproducing loblolly pine stands, namely, winter burning and shelterwood cutting, singly and in combination. This report presents results of those treat-

ments, and compares them in relation to the chemical tools and other treatments that are now being used to favor pine on the Eastern Shore.

Study Area

The study was established in 1952 in a 47-year-old, old-field pine stand of about 41 acres in the Pocomoke State Forest, Worcester County. A light cut for piling had been made among the overstory trees during World War II.

As is usual in such stands, the overstory was mostly loblolly pine, with a dense understory of several hardwood species (fig. 1). Among the stems of all sizes, hardwoods predominated, accounting for 81 percent.

Red maple was the most abundant of the hardwood species, but sweetgums, hollies, blackgums, and black oaks(black, water, and willow oaks) also were common. Other hardwoods included white oak and swamp chestnut oak, sweetbay, and occasional yellow-poplars (table 1, in Appendix).

The hardwoods predominated among stems less than 6 inches in diameter, and were especially numerous among 3-inch and smaller stems. Most of the pine reproduction, about 1,200 seedlings per acre, was relatively young and only a few inches tall.

Methods

The 41-acre study area was divided into 8 treatment plots of about 5 acres each. In the center of each plot a 1-acre subplot was established for studying changes in stand composition. These subplots provided most of the study data, and are referred to below simply as plots.

In the 1-acre plots all trees 0.6 inch d.b.h. (diameter breast high) and larger were tallied by 1-inch diameter classes and species in 1952, before any treatments were made, and periodically thereafter to record treatment effects. Smaller trees were tallied at the same times on 30 permanently marked milacre quadrats in each plot.

Treatments to condition the stand for pine regeneration were applied at various times before a seed-tree cutting was made in 1958. Each of the following treatments was carried out on two 5-acre plots:

- Prescribed burning on 23 March 1953 and on 3 April 1956.
- Shelterwood cutting—a commercial cutting of pine pulpwood between 1 January and 31 March 1957, followed by the poisoning of hardwoods 3 inches d.b.h. and larger in early April 1957.
- A combination of the above treatments.
- None (control plots).

In both prescribed fires the usual height of flames was about 2 feet. They generally consumed the litter and part of the F layer of the forest floor, but did not burn into the H layer. All burning was done when the burning index was about 20 and when winds did not exceed 6 miles per hour; all fires were set to burn with the wind.

The harvest of pine pulpwood in 1957, mostly from the smaller overstory trees, removed about 20 percent of the pine basal area—31 square feet per acre of the total of 155 square feet of pine basal area per acre tallied in 1956. The cutting yielded 5.24 units of 180 cubic feet each per acre. The stumpage price was $3 a unit, a return of $15.72 an acre.

Poisoning was done by applying 2,4,5-T (8 pounds acid equivalent per 100 gallons of No. 2 fuel oil) in ax frills. A State Forest crew of four men did this work at an average cost of $8.41 per acre ($0.71 for material, $7.70 for labor at $1 per man-hour). The stumpage return from the pulpwood sale was sufficient to pay both this cost and the cost of the prescribed burning.

On 3 September 1958 the State of Maryland sold the remaining timber with the stipulation that all except marked seed trees (about 6 per acre) be removed by 1 April 1959, and that the seed trees be removed the following year. The main cutting actually was completed by mid-February 1959, and the seed trees were taken out in late November the same year. Most of the skidding was done with crawler tractors.

Results

PINE REPRODUCTION

Advance Reproduction

All treatments made prior to the 1958-59 seed-tree cutting favored the establishment of pine reproduction: plots prescribe-burned and shelterwood-cut gained 5,467 seedlings per acre between 1952 and 1958, and stocking by milacre quadrats increased from 37 percent to 93 percent (table 2, Appendix). The stocking in plots that were only prescribe-burned or only shelterwood-cut also increased, but not nearly so much as under the combination treatment. During the same period, the stocking of pine reproduction in the untreated plots decreased slightly.

These changes are, of course, net changes. In loblolly pine reproduction under a stand, there is naturally a continual turnover from some seedlings dying and from new ones starting. Besides this natural turnover, the prescribed burns temporarily wiped out all pine reproduction, and logging disturbances in the pulpwood cutting eliminated many seedlings. However, both treatments were followed by the establishment of far more new seedlings than were present before.

Effect of Seed-Tree Cutting on Advance Reproduction

The 1958-59 logging eliminated most of the advance pine reproduction—94 percent of it for all plots combined. For the combination treatment, seedlings per acre were reduced from 6,517 to 500, and stocked quadrats from 93 percent to 32 percent. For the other treatments, which had considerably less advance reproduction, only an insignificant amount of stocking remained after the cutting (table 3, Appendix).

Survival of advance pine reproduction through the logging operation was, of course, greatly affected by the amount of disturbance. No seedlings survived in loading areas, haul roads, skid trails, or heavy slash accumulations. Most of the surviving seed-

lings were found in spots where the forest floor had not been disturbed and little or no slash had been deposited.

Logging disturbances were severe and extensive in this operation—probably more so than in many Eastern Shore cuttings—both because the stand contained a large volume and because more than half of the trees were put into piling. Piling stems were peeled in the woods, thus adding to the volume of slash and increasing the ground disturbance. Slash covered 65 percent of the area, and much of it was relatively deep. Skid trails, haul roads, and loading areas covered about 33 percent. Skid trails had severely disturbed forest floors, and disturbances on the haul roads and loading areas were even greater. There the forest floor was ground into the soil, the soil was severely churned, and water stood on the surface during the winter and early spring.

About 49 percent of the seedlings that survived the logging died during the following summer. Some of this mortality could be attributed to logging injuries and some to the great change in environment, but most of it resulted from damage by Pales or similar weevils.

Consequently, advance pine reproduction contributed little to restocking the cutover area, even though it had ranged as high as 6,500 seedlings per acre and 93-percent stocking by milacre quadrats before the harvest cutting (table 3, Appendix).

Subsequent Reproduction

The 1958 crop of pine seed was very light in the study area. Based on 16 1/16-milacre seed traps, maintained from 3 November to 27 April, the seedfall was only about 29,000 seeds per acre, of which 19,000 were sound. By way of comparison, this catch of sound seed was only 13 percent of that from a good crop in 1951 that was sampled in another seed-tree cutting (3). Despite the light crop in the present study, average stocking by treatments in the fall of 1959 was fairly good: 2,083 to 2,450 pine seedlings per acre, and 75 to 82 percent by milacre quadrats.

This 1959 stocking suffered an overwinter loss of 24 percent of the seedlings and 14 percent in terms of stocked quadrats.

Disturbances incident to the harvest, in November 1959, of the six seed trees per acre were largely responsible for these losses. Pales or similar weevils caused only a small amount of mortality during the 1960 growing season.

A large increase in pine reproduction occurred in 1960 as a result of the 1959 seed crop. Even though the seed trees were removed before all the 1959 seeds had fallen, seed-trap catches indicated that 66,000 pine seeds per acre, of which 54,000 were sound, had been distributed. In late August 1960 the average stocking by treatments was 7,000 to 9,200 pine seedlings per acre, with 93 to 97 percent of the quadrats stocked.

In the fall of 1961, 2 years after the seed trees were removed, pine reproduction still was plentiful in all treatments at 7,000 to 8,900 seedlings per acre, and some seedlings were up to 5 feet tall. However, appreciable differences already were appearing among treatments in the degree of dominance exhibited by the young pines in relation to competing hardwoods. For the three treatments collectively, the pine seedlings definitely were free to grow on 55 to 65 percent of the quadrats, whereas with no treatment before the seed-tree cutting, seedlings were free to grow on only 30 percent of the quadrats. We estimate, on the basis of these early results and general silvical observations in the region, that:

1. *The combination treatment* used before seed-tree cutting will be sufficient to produce another predominantly pine stand; that is, 85 to 90 percent of the stems in the next overstory will be pines.

2. *Single treatments* will be somewhat less effective: after the shelterwood cutting, possibly 75 to 80 percent of the next overstory will be pines; and after the prescribed burning, possibly 65 to 70 percent will be pines.

3. *Where no conditioning treatment* was used, pines may form 45 to 50 percent of the next stand.

The differences described above, and those anticipated in the future, are not direct effects of conditioning or harvest-cutting

treatments on the amount of pine reproduction; rather, they are effects of those treatments on the hardwood tree and shrub competition.

HARDWOOD COMPETITION

Effect of Conditioning Treatments

During the first 4 years of the study the only treatments were two prescribed burns, in 1953 and 1956, on four of the plots. These burns reduced the numbers of hardwoods larger than 0.5 inch d.b.h. by 65 percent. Meanwhile hardwoods of this size on unburned plots increased by 8 percent. The burns were most effective on stems in the smaller size classes (fig. 2). By diameter classes, 1-inch stems were reduced by 86 percent, 2-inch stems by 29 percent, and 3- to 5-inch stems by only 0.4 percent. However, numbers of stems less than 0.6 inch in diameter were not greatly affected because enough new seedlings started and enough top-killed larger stems sprouted after the burns to roughly balance the kills in this class.

Bark characteristics also influenced fire effects: thin-barked species such as beech, yellow-poplar, sweetbay, red maple, and holly succumbed to fire more readily than such thick-barked species as sweetgum and the oaks.

Still bigger differences in hardwood understories developed after the shelterwood treatment was applied in 1957. By 1958 the number of hardwood stems larger than 0.5 inch in diameter had decreased in the combination treatment to 15 percent of the number present in 1952. The shelterwood treatment alone reduced the hardwoods of this size class to 57 percent of their 1952 number. Some further hardwood decline occurred under the prescribed-burning treatment alone—from 35 percent of the 1952 number in 1956 to 27 percent in 1958. Untreated plots still had 108 percent of the original number of stems, as in 1956.

Effect of Seed-Tree Cutting

The severe disturbances associated with the heavy cutting of 1958-59 greatly reduced the hardwoods of all sizes except those in the smallest class (less than 0.6 inch in diameter). Hardwoods in the 1- and 2-inch diameter classes were reduced 77 to 89 percent between the 1958 and 1959 tallies; differences in abundance of hardwoods of this size due to previous plot treatments had little or no effect on the reduction percentages. Hardwoods 3 inches and larger in diameter were reduced 43 to 47 percent in the untreated and burned-only plots. In the shelterwood and combination plots, where 3-inch and larger trees had been poisoned in 1957, the reductions were 89 and 87 percent. (For actual numbers of stems involved above, see table 4.)

Numbers of stems less than 0.6 inch in diameter were greater in 1959 than before the logging, except under the combination

Figure 2.—Plot prescribe-burned in 1953 and 1956, as it appeared in 1958 just before the seed-tree cutting. Note the relative openness in the lower part of the understory (between 2 and 10 feet above ground) compared to the unburned area shown in figure 1.

treatment. For the control and burned-only treatments, the increases were around 6,000 stems per acre (table 4). These increases came from new seedlings, especially red maple and sweetgum, that started after the logging, and from the sprouting of larger stems that had been cut or broken. Small stems increased only slightly in 1959 under the shelterwood treatment, and decreased under the combination treatment, perhaps because substantial increases had already occurred in these plots after the 1957 shelterwood cutting.

Removal of Seed Trees

The removal of seed trees in November 1959 caused much less damage to hardwoods than the heavier cutting of the previous year. Consequently, most of the change between the 1959 and 1960 tallies reflected growth in size of already established stems. In all treatments the number of hardwoods larger than 0.5 inch in diameter increased (table 4).

Cumulative Effect of Treatments

Even though logging damage in the harvest cuttings partly obliterated the differences among prelogging treatments, the 1960 tallies still showed marked differences in numbers of hardwoods larger than 0.5 inch in diameter, as tabulated below (figs. 3 and 4):

Treatment	*1- to 3-inch stems (No. per acre)*	*4-inch and larger stems (No. per acre)*
Prescribe-burned and shelterwood-cut	39	4
Shelterwood-cut	86	4
Prescribe-burned	65	58
None	147	59

The poisoning done in connection with the shelterwood cuttings in 1957 had reduced the number of larger hardwoods to 4 per acre, and most of these were nearly dead (fig. 4). In contrast, in plots not so treated there were 58 or 59 4-inch and larger stems per acre—enough to capture the crown space on possibly 30 percent of the area (fig. 3).

Figure 3.—One of the plots that received no conditioning treatment, as it appeared in the spring of 1960, a few months after seed trees were removed. Note the hardwoods and pulpwood-size pines left in the area.

Figure 4.—One of the plots that had been shelterwood-cut, as it appeared the spring of 1960, a few months after seed trees were removed. Note the absence of residual pines and hardwoods as compared to figure 3.

Treatment effects on numbers of 1- to 3-inch hardwoods in 1960 were somewhat different, mainly because trees in this size category were not poisoned. (Poisoning in 1957 was restricted to 3-inch and larger trees, and most of the 3-inch trees of 1960 presumably were less than 3 inches in diameter in 1957.) So, the 1- to 3-inch hardwoods present in 1960 reflect the single and combined effects of only the burning and cutting treatments, namely: fewest trees in the combination treatment, most trees in the untreated controls (fig. 5), and intermediate numbers of trees

Figure 5.—A thicket of small hardwoods and shrubs, relatively undisturbed by the harvest cuttings. Three years after seed trees were removed, such thickets were most common in plots that had received no conditioning treatments, although a few occurred also in the shelterwood-cut plots.

in the two single treatments. Although hardwoods of this size cannot so quickly expand their crowns and prevent pine reproduction in openings from becoming dominant, their lead is sufficient that nearby pines often will be unable to overtake them.

From 1960 through 1962, most of the differences in hardwood competition continued to be in stems larger than 0.5 inch d.b.h.; however, some residual effects of the conditioning treatments on amounts of smaller growth were apparent, particularly between burned and unburned plots. On the unburned plots, especially the check plots, dense brushy hardwood thickets often occupied spots where little or no logging disturbance had occurred (fig. 5). Although some 1- to 3-inch stems commonly were present, the distinguishing characteristic of the thickets was a dense growth of smaller material. Such thickets seriously interfere with establishment and growth of pine reproduction. Similar thickets had not developed on the burned plots.

The extent to which the larger residual hardwoods and thickets of smaller hardwood growth dominated the sites after harvest cutting varied both among and within treatments. Some spots and small patches that were sufficiently open to permit successful pine regeneration could be found in all plots. However, only in the combination conditioning treatment was well distributed, free-to-grow pine reproduction established in 1962 over plot areas as a whole (fig. 6).

Discussion

There is little reason to be concerned about advance pine reproduction in Eastern Shore pine stands similar to the stand used for this study. When such stands are cut heavily, logging damage will eliminate the bulk of the advance reproduction, and mortality will be high among seedlings that do survive the logging because of damage by Pales (and possibly other) weevils.

Damage by these weevils is greatest on small established seedlings or on newly planted seedlings; damage to seedlings during their first year from seed is negligible (7). Observations on the

Figure 6.—Well distributed, free-to-grow pine reproduction characteristic of plots that had received the combination of conditioning treatments. View below was taken 3 years after seed trees were removed.

Eastern Shore indicate that the damage is most important in areas planted within a few months after cutting, and where heavy reliance on pine regeneration is placed on the planted seedlings.

To bypass the problems of logging and weevil damage to advance reproduction, regeneration after logging seems logical. A simple and practicable way to obtain this regeneration is by use of seed trees. In this study, although the 1958 crop of pine seed was very light, 6 seed trees per acre still provided more than 2,000 seedlings per acre, and stocked 75 to 82 percent of the milacre quadrats. The good 1959 seed crop raised the number of pine seedlings to 7,000 or more per acre, and the stocking to

93 to 97 percent. Despite the usual ups and downs in pine seed crops that are typical of most forest trees, we believe that seed-tree cuttings similar to those used in this study will practically always provide more than enough pine reproduction.

Conditioning stands for regeneration before the final harvest cutting is advisable even though most of the resultant advance pine reproduction does not survive. There are several reasons for this conditioning:

1. Most important is the fact that, with adequate conditioning, little work will be needed after the cutting to regenerate another pine stand. Furthermore, conditioning treatments can be made with less regard to specific timing than in the treatment of already cutover areas.

2. Conditioning—assuming it includes as an integral part a pulpwood cutting of the smaller trees in advance of the main harvest cutting for sawlogs or piling—salvages trees that otherwise would die before the final cutting and, moreover, the pulpwood will often pay the cost of other cultural measures. Mortality among the smaller (overtopped and intermediate) trees of pulpwood size in mature or nearly mature pine stands is considerable. In our study, 5 percent of the overstory pines died during the first 4 years, before any cutting was done; during the next 2 years, after the shelterwood cuttings were made, mortality was 3.7 percent in the uncut plots and 1 percent in the cut plots. Furthermore, when no advance cutting for pulpwood is done, many of the smaller living trees are broken or otherwise damaged in logging the larger trees. And, if left standing after a commercial clearcutting, these smaller trees—damaged or not—grow but slowly and suffer high mortality: in one study 31 percent of such stems died in 4 years and survivors grew only 0.6 inch in diameter; the net change in basal area was a loss of 19 percent (4).

3. Conditioning that includes both an advance cutting for pulpwood and measures to reduce the undergrowth improve logging conditions for the final harvest cutting and can be expected to induce operators to pay a higher price for the stumpage. A similar

conclusion has been reached in South Carolina: there logging costs in a relatively brush-free area in a loblolly pine stand were $2.29 less per thousand board feet of sawlogs, and $1.50 less per cord of pulpwood, than in an untreated part of the same stand (*6*).

In conditioning Eastern Shore pine stands for regeneration, the emphasis should be on reducing hardwood trees and shrubs. As this study shows, stimulation of cone production and seedbed improvement usually are not as important as providing conditions that are open enough to enable pine seedlings to gain dominance. A partial exception to the above may be found in very dense, previously unthinned stands. There a light cutting of sawlog or piling trees from the upper canopy, done at least 3 years before the seed-tree cutting, would be advantageous for stimulating cone production.

Several alternative methods are available as conditioning treatments. Some of those methods are quite new and were not accepted practices on the Eastern Shore when the present study was designed. For killing relatively large hardwoods, recently tested injector treatments (*1*) are more effective than the ax-frill techniques formerly used. For eliminating small hardwoods, the light winter fires of this study were adequate, but even better kills probably could be achieved by either repeated summer fires, as used by Lotti et al. (*6*), or by mistblower treatment with 2,4,5-T (*2*). Disking is another possible treatment, but this is less generally useful because overstory trees often are so dense that a tractor-disk outfit cannot be maneuvered effectively, and also because even the heavier disks eliminate relatively few stems in dense hardwood thickets.

Summary

In 1952 a study of prescribed winter burning and shelterwood cutting for regenerating loblolly pine was started in a commercially mature pine stand on the Eastern Shore of Maryland. Burns were made in March 1953 and April 1956. The shelterwood cutting was a commercial cutting of pine pulpwood early in 1957, followed by the poisoning of hardwoods 3 inches d.b.h. and larger. Then, in the fall and winter of 1958-59, all plots received a seed-tree cutting, and in the following November the seed trees were removed.

This report summarizes results through the second growing season after the seed trees were cut. It shows that, although the amount of advance reproduction of loblolly pine can be increased by prescribed winter burning and shelterwood cutting, little of it will survive the disturbances caused by logging a heavy timber stand. However, leaving seed trees for 1 year after cutting should usually give sufficient regeneration—in this study about 2,000 seedlings per acre were present in 1959, and 7,000 to 9,200 per acre in 1960.

Conditioning treatments applied in advance of the main harvest cutting are of value mainly for improving conditions for pine regeneration that starts after the cutting, thereby increasing the proportion of pine in the next stand. Treatment benefits come about largely from reduction of the hardwood competition. Winter fires can greatly reduce the number of small hardwoods, particularly those smaller than 2 inches in diameter. Poisoning can eliminate the larger ones. A shelterwood cutting of pulpwood-size pines done in advance of the main harvest cutting will further reduce understory hardwoods, and also salvage many trees that otherwise would be lost by natural mortality or by breakage during the main cutting. Moreover, the pulpwood usually will pay for the burning and chemical treatments. Without conditioning treatments, the next stand will probably be about a 50-50 pine-hardwood mixture; with adequate conditioning before the main harvest cutting, the next stand should run 85 to 90 percent pine.

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Appendix

Table 1.—*Stand composition at start of study, in number of stems per acre*[1]

Species	Size class, inches d.b.h.					Total
	Less than 0.6	1-2	3-5	6-10	11-20	
Pines	1,208	0	1	133	112	1,454
Black oaks	371	5	—	—	—	376
White oaks	117	2	—	2	—	121
Sweetgum	821	111	32	12	3	979
Red maple	2,862	583	70	4	—	3,519
Blackgum	250	114	2	1	—	367
Holly	429	106	16	—	—	551
Sweetbay	146	16	—	—	—	162
Yellow-poplar	—	1	—	1	—	2
Redcedar	—	7	3	—	—	10
All hardwoods	4,996	938	120	20	3	6,077
All species	6,204	945	124	153	115	7,541

[1]Values are rounded off, so widely scattered single trees, as of yellow-poplar, do not show in all classes. Includes all stems larger than 0.5 inch d.b.h.; below that size only the largest member of a sprout clump is included, along with all seedlings.

Table 2.—*Pine reproduction in 1952 and 1958, by treatments*

Treatment	1952	1958	Change, 1952-58
NUMBER OF SEEDLINGS PER ACRE			
Prescribe-burned and shelterwood-cut	1,050	6,517	+5,467
Shelterwood-cut	1,733	2,633	+900
Prescribe-burned	416	2,133	+1,667
None	1,633	1,033	—600
PERCENT OF MILACRE QUADRATS STOCKED			
Prescribe-burned and shelterwood-cut	37	93	+56
Shelterwood-cut	47	68	+21
Prescribe-burned	18	72	+54
None	45	38	—7

Table 3.—*Advance pine reproduction before the seed-tree cutting, just after the cutting, and at the end of the first growing season*

Treatment	Advance reproduction per acre			Milacre quadrats stocked		
	Before cutting	Just after cutting	After the first growing season	Before cutting	After cutting	After one growing season
	No.	*No.*	*No.*	*%*	*%*	*%*
Prescribe-burned and shelterwood-cut	6,517	500	283	93	32	22
Shelterwood-cut	2,633	117	67	68	7	3
Prescribe-burned	2,133	100	0	72	8	0
None	1,033	33	33	38	3	3

Table 4.—*Number of hardwood trees per acre, by size class, treatment, and year*

Year	Size class, inches d.b.h.				
	Less than 0.6*	1-2	3-5	6+	All sizes
PRESCRIBE-BURNED AND SHELTERWOOD-CUT					
1952	4,900	821	146	30	5,897
1958**	13,500	62	52	33	13,647
1959**	8,833	14	7	4	8,858
1960**	7,567	33	8	2	7,610
Change, 1952-60	+2,667	—788	—138	—28	+1,713
SHELTERWOOD-CUT					
1952	5,917	1,030	122	22	7,091
1958**	7,200	578	69	22	7,869
1959**	7,700	62	7	3	7,772
1960**	6,050	79	9	2	6,140
Change, 1952-60	+133	—951	—113	—20	—951
PRESCRIBE-BURNED					
1952	4,000	1,044	114	16	5,174
1958	5,917	159	137	21	6,234
1959	11,917	26	71	13	12,027
1960	10,567	43	64	16	10,690
Change, 1952-60	+6,567	—1,001	—50	0	+5,516
NO TREATMENT					
1952	5,167	860	103	17	6,147
1958	4,633	911	125	26	5,695
1959	10,817	115	70	16	11,018
1960	10,233	119	69	18	10,439
Change, 1952-60	+5,066	—741	—34	+1	+4,292

*Seedlings and sprout clumps.
**Includes poisoned trees that showed any life above breast height.

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CULL DEVELOPMENT

Under All-Aged Management of Hardwood Stands

by

GEORGE R. TRIMBLE, JR.

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RALPH W. MARQUIS, DIRECTOR

CULL DEVELOPMENT

Under All-Aged Management of Hardwood Stands

The Author —

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The Question of Cull

MOST of our present stands of eastern hardwoods grew up — without benefit of silviculture — after the original timber was cut off some 50 to 100 years ago. Through the years since then, these stands have been subjected to varying degrees of damage and attrition from fire, grazing, insect and disease attack, and further cutting.

Many of these stands are uneven-aged. They are composed of leftovers from past cutting operations, plus some second growth, plus a scattering of trees of shade-tolerant species that have found their way into the overstory through openings created when older trees were cut or died from natural causes. In their wild state, these stands contain many defective trees — culls[1] —

[1]In the Northern Appalachian region, with which this report deals, culls are defined as follows: in the size class from 5 to 11 inches d.b.h., any tree that does not have a sound 12-foot section to a 4-inch top, inside bark; or, for stems too small to make 12 feet to a 4-inch top, any tree that does not have a potentially sound 12-foot section. In the size class larger than 11 inches d.b.h. (sawtimber trees), any tree that is not at least 50 percent sound to an 8-inch top, inside bark, or does not have a 16-foot log of sound merchantable material. Besides rot, sweep or extreme roughness can make a log unmerchantable and thus make the tree a cull.

which have no market value now or in the foreseeable future, and which occupy space that otherwise could be producing good stems (fig. 1).

Figure 1.—An old residual beech sawtimber cull. The workman is applying ammate crystals in notches to kill the tree.

Since the advent of the Civilian Conservation Corps in 1933, and especially since World War II, large areas of the eastern hardwood forests have been put under some degree of management. In most stands culls are a real problem. One of the first steps in a management program is to eliminate these worthless trees. Some stands are so cluttered with culls that complete removal of the overstory and regeneration of a new stand may be the best course of action. However, these are extreme cases:

usually the treatment can be less drastic, so that a manageable stand is left after cull removal.

But after the culls have been removed, and a management program has been begun, new cull trees will in time develop. The question is: how much of a job will it be to keep such stands free of culls?

A good indication of the size of this job is provided by records for a number of areas on the Fernow Experimental Forest near Parsons, West Virginia, where the development of cull has been studied in the course of experimental selection management practices used by the Northeastern Forest Experiment Station of the U. S. Forest Service.

The Study Area

The Fernow Forest was virgin timber until about 1905. Cuttings at that time varied between clear-cutting and high-grading for sawlogs. Controlled experimental cuttings were begun in 1949. At that time the Forest had been protected from fire, grazing, and cutting for about 30 years.

Before it was placed under management, the Fernow Forest had 10 to 20 percent of its total sawtimber stand volume in cull trees. Although this is a lot of cull, the percentage of the volume in cull trees probably was lower here than in most Appalachian woodlands.

There are 10 areas on the Fernow Forest for which cull development records are available for periods of 5 to 10 years (table 1). Six of these areas are under *intensive* selection management, a system in which all trees 5 inches d.b.h. and larger are considered in stand treatments, and in which all culls down to a 5-inch minimum diameter are killed. Four of the areas are under *extensive* selection management, in which stand treatments and cull removal are applied only to trees larger than 11 inches d.b.h. One-hundred-percent inventories, made on these areas before and periodically after the beginning of management, show the extent of cull-tree development under the two management programs.

Table 1.—Study areas examined for cull-tree development under selection management

Area	Acres	Site[1] index	First harvest cut under management	Cutting cycle	Original volume per acre			
					Merchantable		Cull	
					5-11 in.	11 in. +	5-11 in.	11 in. +
	No.	*Feet*	*Year*	*Years*	*Cu. ft.*	*Bd. ft.*	*Cu. ft.*	*Bd. ft.*
INTENSIVE SELECTION MANAGEMENT								
18A	29	80	1952	[2]5	1,097	11,941	9	512
18B	42	70	1952	5	643	14,567	11	2,812
18C	45	60	1952	([3])	572	10,106	33	3,801
8D	5	80	1949	5	508	12,545	14	1,208
Tier A	15	90	1954	10	853	13,810	6	1,108
Tier C	15	60	1956	10	794	6,164	37	950
EXTENSIVE SELECTION MANAGEMENT								
16A	24	80	1951	20	1,061	14,488	2	496
16B	34	70	1951	10	919	11,883	3	1,527
16C	19	70	1951	10	539	12,119	9	2,788
8C	5	80	1949	10	404	13,271	18	1,281

[1]Site index for oak from Schnur, G. L. YIELD, STAND, AND VOLUME TABLES FOR EVEN-AGED UPLAND OAK FORESTS. U. S. Dept. Agr. Tech. Bul. 560, 1937.

[2]Long-range plan sets cycle at 5 years, but second cut is not planned until 1964.

[3]Flexible: length of cycle determined by growth.

Results

Effect of Time after Logging and Treatment

The development of new cull trees after the initial elimination of culls at the time of the first management cut has been very slow (table 2). For all study areas, which include 233 acres all together, the average per-acre volume in sawlog-size cull trees after 5 years was only 46 board feet — a development rate of 9 board feet per acre per year. For the 92 acres for which we have 10-year records, the average per-acre volume in sawlog culls after 10 years was 108 board feet — a development rate of 11 board feet per acre per year.

Figure 2.—A 14-inch cucumber tree that has become a cull because of rot spreading from 10-year-old logging injuries.

Table 2.—Number and volume of cull trees per acre that developed after the original cull elimination under selection management

Area	Cull trees				Volume of cull trees			
	5-years after		10-years after		5-years after		10-years after	
	5-11 in.	11 in. +	5-11 in.	11 in. +	5-11 in.	11 in. +	5-11 in.	11 in. +
	No.	*No.*	*No.*	*No.*	*Cu. ft.*	*Bd. ft.*	*Cu. ft.*	*Bd. ft.*
INTENSIVE SELECTION MANAGEMENT								
18A	1.7	[1]0.1	2.1	0.3	7	6	10	38
18B	1.9	[1] .1	—	—	8	28	—	—
18C	4.5	.4	—	—	20	65	—	—
8D	.0	.0	1.2	.0	0	0	8	0
Tier A	.5	.0	—	—	2	0	—	—
Tier C	2.7	.0	—	—	9	0	—	—
EXTENSIVE SELECTION MANAGEMENT								
16A	4.6	0.3	—	—	25	35	—	—
16B	5.1	.5	2.9	0.8	27	115	18	191
16C	7.0	.6	2.9	.8	34	85	20	121
8C	.6	.0	.6	.0	4	0	4	0

[1]Less than 0.1.

The data indicate — though certainly not conclusively — that cull-tree development in the larger size classes accelerates with time after logging. This is a logical trend insofar as cull is related to logging injuries. Rot develops and spreads from these injuries until it reaches a point where the tree is defined as a cull (fig. 2). In larger trees this deterioration is rather prolonged, and the time lags that are involved could reasonably be expected to result in accelerated cull development with the passing years.

The acceleration in cull development very likely continues longer than the 10-year period of our observations. We know that the volume in cull trees is only a partial measure of the defective material in a stand: many merchantable trees contain rotten or otherwise unusable segments. Much of this defect is a result of logging injuries. The volume of this defective material

Figure 3.—A sweet birch that has become a cull because of cankers.

in merchantable trees probably is greater 5 to 10 years after logging than the volume in trees that have gone completely over into the cull category. And unless harvested soon, many of these damaged merchantable trees can become culls — given a little more time.

On the six intensive selection areas where small as well as large culls were eliminated originally, cull development among stems below sawtimber size was remarkably slow. For all 151 acres in these areas, the average per-acre volume in cull trees of this size class was 11 cubic feet after 5 years. On the 2 areas totaling 30 acres where 10-year observations were made, the average per-acre volume in cull trees went from 6 cubic feet at 5 years to 10 cubic feet at 10 years. This is cull-tree development at a rate of only about 1 cubic foot per acre per year for the 10-year period.

On the four extensive selection areas, where small culls were not killed originally, average cull-tree volume in the small diameter range went from 5 cubic feet before cutting to 27 cubic feet 5 years later. At the end of the second 5-year period, the average had dropped to 17 cubic feet.

The records for the extensive selection areas indicate that shortly after logging a number of 5- to 11-inch culls developed. Then their numbers declined. What happened to these culls between the 5- and 10-year measurements? Did they grow into the sawlog class, or did they die out? Casual observation leads us to speculate that many of the 5- to 11-inch culls died out, at least among those in the lower part of this size range. These defective understory trees were of lower than average vigor. Weakened as they were by injury and, in many instances, also by disease, most of them apparently did not last long. On the other hand, a substantial proportion of the larger culls in this size class (9- and 11-inch) probably moved up as culls into the sawlog class.

Observations on a number of small culls leads us to believe that logging damage was a major cause of the defects that degraded them to cull status. However, in the case of sweet birch, we found that many trees became culls as a result of Nectria canker attacks (fig. 3).

Relationships between Cull Development and Size of Culls Killed Originally

Under extensive selection management, only the cull trees of sawlog size (larger than 11 inches d.b.h.) were killed; whereas under intensive selection management all culls over 5 inches d.b.h. were killed. So, at equal periods of time after initial treatment, we could reasonably expect greater cull volumes under extensive management in both the sawlog and under-sawlog size classes. The greater volume in the sawlog class would come from ingrowth by culls that were less than 11 inches d.b.h. when the stand was treated.

The data, summarized in table 2, support these expectations. Since 10-year observations were obtained on only two areas under intensive management, the best evidence came from the 5-year measurements. Five years after cutting and cull treatment under intensive management, cull volume was 11 cubic feet in 5- to 11-inch trees, and 28 board feet in the sawlog portion of the stand. Under extensive management, comparable figures were 27 cubic feet and 78 board feet.

Effect of Species

In mixed stands, such as those on the Fernow Forest, culls may reasonably be expected to develop more commonly in some species than in others, either because of greater susceptibility to disease (rots and cankers) or because of greater susceptibility to logging damage. One measure of this expected tendency is to compare the relative frequency of different species in the merchantable stand with their relative frequency among the culls. This was done.

The species that consistently appeared in higher proportions among the culls were: sweet birch, sassafras, Fraser magnolia, cucumber tree, basswood, and red maple. For example, in one compartment, sweet birch and basswood were the two species most numerous among the culls; yet they were fourth and fifth in numerical order of abundance in the merchantable stand. On

another area, sassafras was the most numerous among the culls but ranked fifth in the merchantable stand. In contrast, the oaks were in relatively smaller proportions among the culls.[2]

One obvious reason for the large proportions of sweet birch and sassafras among the culls was the high incidence of canker on these species.

Summary and Conclusion

Cull-tree development was observed at intervals of 5 and 10 years after selection management was begun in hardwood stands in West Virginia. The first steps in management were a logging operation based on selection marking, followed by treatment to eliminate cull trees. On some areas all culls 5 inches d.b.h. and larger were treated; on others only the 11-inch and larger culls were treated. The rate at which new culls developed was related to time after logging and cull treatment, size range of culls treated, and species.

The development of new culls during the 5- and 10-year intervals after the initial elimination of culls was remarkably slow. Logging damage to residual trees appeared to be the principal reason for development of the new culls that did appear, particularly in the sawlog portion of the stands. If the old culls had been killed without an accompanying logging operation, the subsequent development of new culls no doubt would have been even slower.

For eastern hardwood stands similar to those on the Fernow Experimental Forest, the conclusion reached from this study is that cull-tree elimination need be no more than a minor and periodic operation after one thorough initial treatment has been made.

[2]A study of log defects in the southern Appalachians revealed a similar relationship among species; that is, oak logs were found to have less defect than logs of most other species. *See* Jiles, Robert A. SCALABLE DEFECTS IN HARDWOOD LOGS. Tennessee Valley Authority Div. Forestry Relat. Tech. Note 25, 1956.

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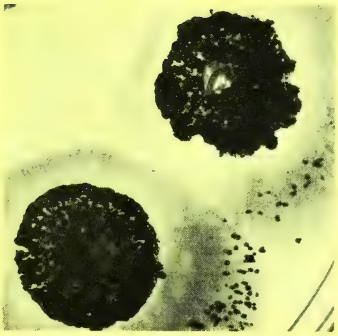

Fungus and Insect Injury to Yellow Birch Seeds and Seedlings

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CLEMSON COLLEGE
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Fungus and Insect Injury to Yellow Birch Seeds and Seedlings

Introduction

BECAUSE yellow birch (*Betula alleghaniensis* Britt.) is one of the most valuable species in our northern hardwood forests, much attention has been turned toward methods for obtaining better regeneration of this species after logging. Although regeneration of these trees is influenced by many factors, one of the most important is an abundance of healthy seeds. And one problem that has recently been recognized is the damage that is done to seeds and seedlings by fungi and insects.

Past research has not provided much guidance on this problem. The *Woody-Plant Seed Manual (U.S. Forest Service 1948)* and other publications either state that insects and diseases cause very little damage to yellow birch seeds *(Godman and Krefting 1960)*, or ignore the subject.

In a recent publication on seed-borne diseases *(Noble et al. 1958)* the fungus *Ciboria betulae* is listed as being seed-borne on

other species of birch, and *Septoria betulae* is thought to be; but proof is lacking. Sokoloff *(1940),* reporting on the work done in 1938 at the Leningrad Seed Control Station, listed 48 species of fungi that had been isolated on malt agar from seeds of American ash, maple, oak, and birch. Some of the fungi isolated were *Coniothyrium olivaceum, Phoma samorarum, Pythium de baryanum, Rhytisma acerinum, Sclerotinia pseudotuberosa,* and *S. betulae.* But Redmond and Robinson *(1954)* reported that no fungi emerged from more than 1,000 yellow birch embryos that were excised and placed on bacto-malt-agar.

As for insect damage, reports in the literature are very scarce. Craighead *(1950)* states that the birch seed midge *Oligotrophus betulae* is the only insect known to cause injury to birch seed.

In 1959 the Northeastern Forest Experiment Station's research unit at Laconia, N. H., began studies of fungus and insect damage to seeds. Observations and preliminary experiments indicated that fungi and insects can cause considerable injury to seeds and seedlings of all northern hardwood species. This paper reports some observations and results of experiments on fungi and insects attacking seeds and seedlings of yellow birch.

Methods

The following materials and methods were used in the experiments.

Seeds to be tested were placed to germinate on a mixture of three parts vermiculite to one part washed sand, after the mixture had been sterilized by autoclaving and then spread out 1 inch thick in aluminum trays. The seeds were watered daily with sterile distilled water. To maintain the seedlings for the duration of the tests, overhead cool-white fluorescent lamps were used to supply 85 foot-candles of light to the surface of the trays from 8 a.m. to 5 p.m. each day.

Standard techniques were used for isolating fungi from inside the seeds and seedlings. The seeds and seedlings were surface-sterilized in a 10-percent solution of commercial Clorox bleach (5.25 percent hypochlorus acid) for 5 minutes, and rinsed in

sterile distilled water in petri dishes. A half milliliter of a 1-percent streptomycin solution was added to the last rinse to arrest the growth of bacteria.

The surface-sterilized seeds and seedlings were placed with sterile tools on a malt-yeast-agar medium in petri dishes. These plates were kept at room temperature for at least 5 days before the fungi growing from the seeds and seedlings were identified.

Results

Injury Caused by Fungi

In a preliminary experiment begun early in 1960, 1,100 seeds free of obvious injuries were selected from a collection made during the fall of 1959 from a single representative tree on the Bartlett Experimental Forest in Bartlett, New Hampshire. This study was directed mainly toward ascertaining fungus injury.

Of the 1,100 seeds tested, 385 (35 percent) germinated within 6 weeks. Of the 385 seedlings produced, 321 appeared chlorotic; and these were cultured to determine whether any fungus was present.

The fungus *Coniothyrium* sp. (tentatively identified as *C. olivaceum*) was isolated from 63 percent of these chlorotic seedlings (fig. 1). At the same time the same fungus was isolated from 84 percent of 220 seeds (picked at random) that had failed to germinate (fig. 2). *Penicillium* spp., *Aspergillus* spp., *Alternaria* sp., *Trichothecium roseum,* and a few other fungi were isolated from a small number of seeds.

(A similar experiment with seeds and seedlings of paper birch (*Betula papyrifera* Marsh.) indicated that *Alternaria* sp. was the principal fungus involved, and *Coniothyrium* sp. was seldom isolated from paper birch.)

The frequency of *Coniothyrium* sp. on the yellow birch seeds and seedlings from the 1-year-old collection warranted a further investigation. To make certain that the seeds were not infected by fungi during storage, a test was designed to make use of seeds immediately after they were collected. The first female strobili

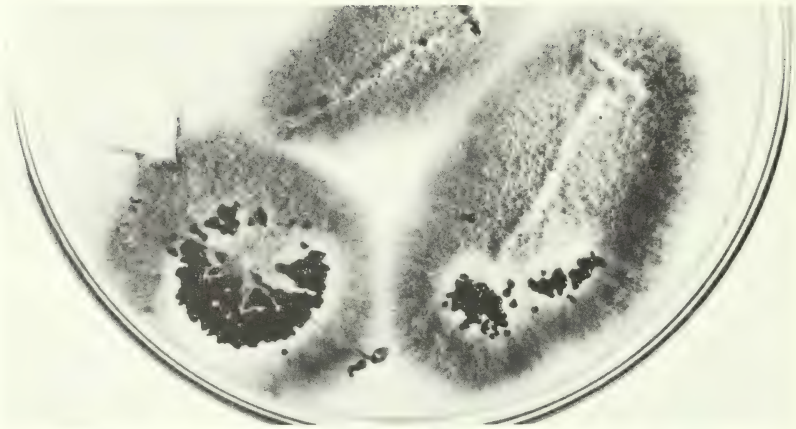

Figure 1.—*Coniothyrium* sp. growing from surface-sterilized seedlings that showed signs of poor vigor. This was the principal fungus found to be infecting yellow birch seeds and seedlings.

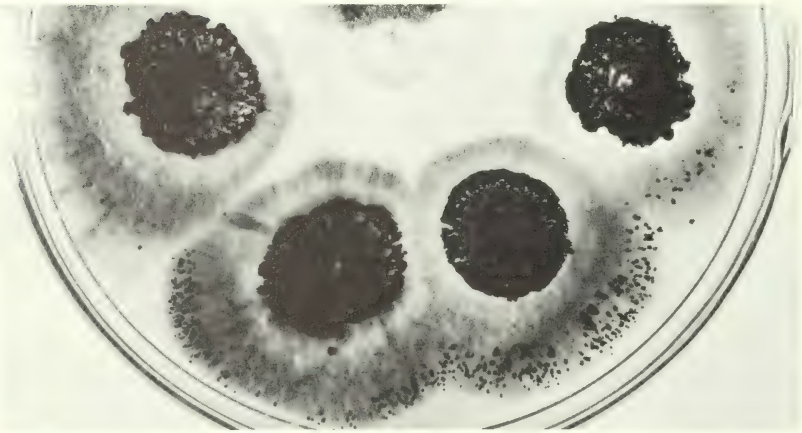

Figure 2.—*Coniothyrium* sp. growing from surface-sterilized seeds that did not germinate after 6 weeks.

(cones) were examined and collected in July 1960. At this time of the year cones are usually green, but many that were collected were partially or completely brown and distorted. Upon dissection of several of these cones in the laboratory, small white larvae were found in them.

Injury Caused by Insects

The larvae found in the cones were identified as a weevil, *Apion walshii* Smith *(Smith 1884).* Identification was made by William E. Waters at the Northeastern Forest Experiment Station's Forest Insect Laboratory at New Haven, Connecticut, and by personnel at the U. S. National Museum in Washington, D. C.

Observations on this weevil were made throughout the summer. Larvae were abundant in July. Adults (fig. 3) were found in August. Active adults were collected as late as November both on the cones and inside them.

The larvae ate around the cones in a spiral towards the tip. Bracts and seeds were injured by the weevils (fig. 4). The continued growth of uninjured seeds and bracts caused the cones to become distorted. Weeviled cones stayed on the trees as long as those that were free of the insects.

By the end of the summer, 30 trees were examined and the weevil was found in cones from all of these. From one-fifth to

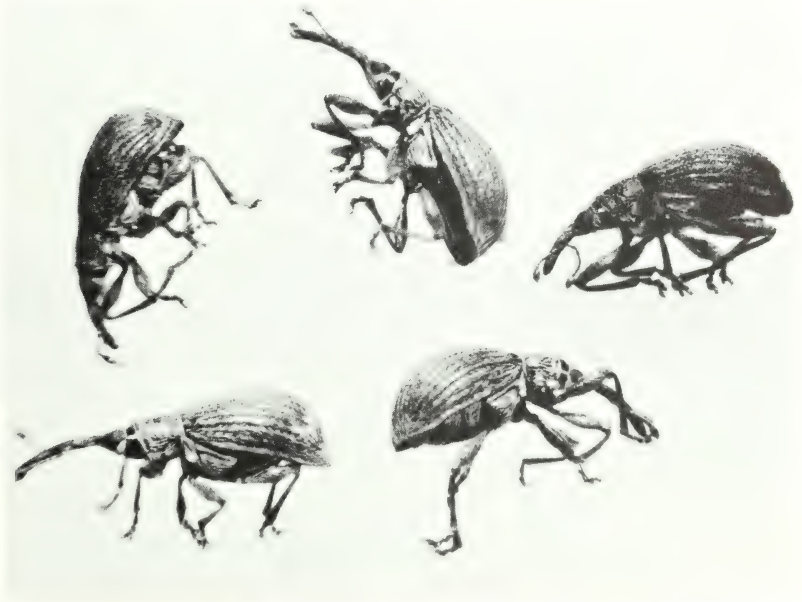

Figure 3.—The weevil *Apion walshii.* Larvae and adults of this weevil were found in many cones of yellow birch.

Figure 4.—Dissected yellow birch cones, showing areas injured by *Apion walshii*.

one-half of the seeds in each weeviled cone had been destroyed (fig. 5). Some trees had a high percentage of their cones injured. The uninjured seeds in the weeviled cones did not appear as healthy as those seeds from cones free of the weevil.

Injury Caused by Fungi and Insects

As a result of these observations, and since so many cones were attacked by weevils, it was thought necessary to alter the study in order to investigate the fungi active in weeviled cones. To this end, 100 dry cones were picked in November 1960 from each of 10 trees that had been cut for several weeks. To

Figure 5.—Top, yellow birch seeds injured by the weevil *Apion walshii*. Center, the culprit. Below, sound seed.

insure a random sample, the dry seeds were mixed in a large paper bag.

The next day, 312 injured seeds picked at random from this collection were placed on moistened filter paper in petri dishes. Fruiting bodies (pycnidia) of *Coniothyrium* sp. could be seen on some of the seeds. All except 23 of these seeds yielded pycnidia of *Coniothyrium* sp. after 5 days. Because of this short incubation period, and because pycnidiospores are produced in a sticky mass only when the pycnidia are moistened, the possibility that some seeds might have been infected by spores from fungi

on other seeds while they were still in the bag was considered slight.

To check on this possibility of contamination, branches bearing obviously injured (weeviled) cones were brought into the laboratory. Each cone was taken separately from the branch, flamed lightly, and placed on the agar medium in a petri dish. This procedure was done with 24 cones. After 2 weeks all yielded *Coniothyrium* sp. Other fungi also grew from the strobili, but no species so consistently as *Coniothyrium* sp.

Adult weevils emerged from some of the cones after 4 weeks.

To determine whether or not fungi were present in or under the seedcoats of the apparently healthy seeds, individual seeds were taken at random from the 10-tree sample and were separated into two groups: apparently healthy (good color and form) and obviously injured (weevil injury and poor color and form). This random separating was done until 200 apparently healthy seeds were obtained. The number of obviously injured seeds taken before 200 apparently healthy seeds were obtained was recorded. The procedure was done 10 times, giving 10 subsamples each containing 200 apparently healthy seeds and a number of obviously injured seeds. The ratio of apparently healthy seeds to obviously injured seeds was 2.5 to 1.

The 200 seeds in each subsample of apparently healthy seeds were individually placed on the sand-vermiculite mixture in a tray. After 25 days, 50 percent of the seeds had germinated. Of the ungerminated seeds, 80 percent had visible fungus mycelium over them. And 44 percent of the seedlings had chlorotic, twisted cotyledons. These seedlings were usually shorter than the others. Microscopic examination of the roots of these seedlings revealed the presence of fungus hyphae.

At this time, 20 of the poorest seedlings from each of the 10 trays were carefully pulled, surface-sterilized, and placed on the agar medium in petri dishes. *Coniothyrium* sp. was isolated from 50 percent of these seedlings (fig. 1). The same fungus was isolated from 90 percent of 72 seeds selected at random that had not germinated (fig. 2).

The same procedure was repeated 1 week later, using 10 seedlings and 20 seeds from each tray. *Coniothyrium* sp. was isolated

from 72 percent of the seedlings and 80 percent of the seeds. And 2 weeks later, 10 of the best-looking seedlings and 10 of the poorest seedlings from each tray were surface-sterilized and placed on the agar medium. *Coniothyrium* sp. was isolated from 56 percent of the poorest seedlings and from 13 percent of the best ones.

Other experiments similar to those described above were conducted with the seeds from the 10 trees and from other trees in the same area, and *Coniothyrium* sp. was always the major fungus isolated.

The high percentage of cones injured by the weevil posed the question of the possible association of *Coniothyrium* sp. with the weevil. The seed crop failure in 1961 prevented further experiments that would have been necessary to prove this association. The only weevils collected were reared in the laboratory from a few cones found on several trees.

In 1962 there was a poor-to-fair seed crop and very few cones were found that were not injured by the weevil. *Coniothyrium* sp. was isolated frequently from uninjured seeds in weeviled cones. The weevils were found for the first time in a few paper birch cones.

Discussion

A preliminary investigation indicated that insects and fungi can cause considerable injury to yellow birch seeds and seedlings.

Coniothyrium sp. was the principal fungus infecting yellow birch seeds and seedlings. The fungus apparently is established in and on the seed before it falls to the ground. The sticky masses of spores forced out of the pycnidia when they are moistened are well adapted for insect dissemination.

The weevil *Apion walshii* was abundant in yellow birch cones. Larvae of this weevil destroyed many seeds. The seeds in the cones attacked by the weevil were usually infected by the fungus *Coniothyrium* sp. The possibility exists that the weevils may disseminate the spores; but proof is lacking.

In 1960, strobili and weevils were abundant; in 1961 both

were scarce; and in 1962 there were many weevils in the few cones produced. If yellow birch cones are essential to the weevils for the completion of their life cycle, then the weevil population probably was greatly reduced in 1961. An abundant weevil population such as that observed in 1960 may not be seen again for several years.

Healthy, unweeviled cones, and healthy seeds from such cones, were included in the collection picked at random, but were not treated separately. A more intensive investigation is needed before the importance of these destructive agents can be determined.

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Five-Year Effects from ROW THINNINGS in Loblolly Pine Plantations of Eastern Maryland

by S. Little and J. J. Mohr

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RALPH W. MARQUIS, DIRECTOR

Five-Year Effects from ROW THINNINGS in Loblolly Pine Plantations of Eastern Maryland

■

YOUNG stands of loblolly and pond pine on Maryland's Eastern Shore ordinarily grow rapidly for the first 15 to 20 years, but then slow down as competition among the dominant trees increases. Similar decreases in growth apparently occur in both plantations and well-stocked natural stands.

Conventional thinnings, removing scattered stems, are not very practicable in such 15- to 20-year-old stands. Too much time is required to select crop trees and mark other trees for cutting. Since many of the trees that should be cut either are unmerchantable or contain only one to three sticks of pulpwood, marking costs must be held down if thinning operations are to break even financially. Moreover, the stand densities of 800 to 1,000 pines per acre make conventional thinnings difficult because many of the cut trees lodge, and the merchantable ones, when down, still are difficult to remove.

Cutting all the trees in selected rows in plantations, or in lanes through natural thickets, would bypass most of these difficulties. Once the appropriate interval between cut rows or lanes was

determined, supervision costs would be greatly reduced. Even if each plantation or stand had to be considered separately for deciding upon interval widths, marking costs still would be far less than in conventional thinnings. Felling and removal costs would also be appreciably less: trees could be felled progressively in the row so that there would be little lodging, and unmerchantable trees and slash could be rolled or dragged to one side, thus opening lanes for removing the pulpwood.

However, there are several questions besides economic feasibility that need to be answered before row thinning can be recommended for loblolly pine stands. These include:

- Will automatic spacing remove too many of the better trees and leave too few good-quality crop trees?
- Will row thinning result in significant increases in wind or snow damage?
- What effect will row thinning have on growth and yield? What row interval is best from the standpoint of (1) quality and number of crop trees left, and (2) growth of these trees and of the stand as a whole? Will such thinning result in the development of trees that are suitable only for sawtimber, but not suitable for piling?

To answer these questions, the Maryland Department of Forests and Parks and the Northeastern Forest Experiment Station of the U.S. Forest Service started a study of row thinnings in 1954. The first 5-year results are described in this report.

The Study

The study areas were in four similar adjoining stands, ranging from 3.0 to 5.2 acres each, in the Wicomico State Forest. The overstory of each stand was composed chiefly of loblolly pines planted at 6- by 6-foot spacing about 1938, plus varying numbers of volunteer pines.

Four treatments were tried: cutting (1) every other row of trees, (2) every third row, (3) every fourth row, and (4) every

fifth row. In some places (mostly in the plots where the first and last treatments above were applied), volunteer pines were so numerous that rows could not be distinguished, and the treatment specifications had to be modified. The following procedures gave a fairly close approximation to the desired degrees of stand opening: for the first treatment, strips 6 feet wide were cut and alternate strips of equal width were left uncut; for the last (every-fifth-row) treatment, strips 10 feet wide were cut and the alternate uncut strips were 20 feet wide.

One of the treatments was applied in each of the four stands. Areas actually treated ranged from 1.5 to 2.6 acres, or about half of the total stand in each instance. The remaining half of each stand served as a check or control area. The specified cutting, including removal of the products, was done between late July 1954 and January 1955.

In studying treatment effects, two approaches were used: (1) comparison of individual tree responses, and (2) comparison of overall stand responses.

Primary emphasis was placed on the responses of individual trees by crown classes. In each of the four check areas, 20 trees of each of three crown classes (dominant, codominant, and intermediate) were selected and tagged, and a like number was similarly selected in each crown class from the released stems in each stand. Also, in the two treatments where every fourth or every fifth row was cut, 20 additional trees were selected in each crown class from the center one or two rows that, for all practical purposes, remained unreleased. Thus, in all, 600 trees were selected and tagged: 240 trees in check areas, 240 trees definitely released by the treatments, and 120 unreleased trees in the treated areas. For each tagged tree, diameter (b.h.) to the nearest 1/10 inch, total height, and length of living crown were measured.

To obtain some stand data, five 0.5-acre plots were established, one under each treatment, and one in a check area. In these plots all stems larger than 0.5 inch d.b.h. were tallied by 1-inch diameter classes and species. In addition, 75 pine crop trees were selected in each plot, marked with paint, and tallied separately. Crop trees were selected on the basis of both tree quality (dominance, form, and vigor) and spacing.

Results

MORTALITY

Row thinning had relatively little effect on mortality during the first 5 years. Both among sample trees and in entire stands, somewhat fewer pines died in most of the treated areas than in the check areas; moreover, somewhat fewer trees died under the heavier thinnings than under the lighter ones. However, the differences were rather small: from 18 percent mortality among all residual pines in the every-other-row treatment up to 30 percent where every fifth row had been removed. Average mortality in the check plot where stand data were taken was 25 percent.

Among sample trees the mortality was considerably lower—only 4.5 percent—because this group did not include overtopped stems. Most of the deaths occurred in the intermediate crown class. A somewhat higher proportion of unreleased intermediate trees died in plots where every fourth or fifth row was cut than in check areas or among released trees.

Table 1.—*Effect of row thinning on average 5-year diameter growth per tree, by crown classes*[1]

Treatment, row cut	Area	Dominant trees	Codominant trees	Intermediate trees
		Inches	*Inches*	*Inches*
Every other row	Treated	1.4	1.2	0.6
	Check	1.0	0.9	0.2
Every third row	Treated	1.3	1.0	0.6
	Check	1.1	0.8	0.3
Every fourth row	Treated: released	1.2	0.7	0.4
	Treated: unreleased[2]	1.1	0.6	0.4
	Check	0.9	0.6	0.2
Every fifth row	Treated: released	1.2	0.9	0.4
	Treated: unreleased[2]	1.1	0.7	0.4
	Check	1.1	0.7	0.4

[1] Crown classes before thinning.

[2] Trees in center of uncut strips, hence not released.

Wind and snow damage did not affect mortality in these plots, even though wet snows during the winter of 1957-58 injured trees in younger plantations (*2*). And although Hurricane Hazel in October 1954 and Hurricanes Connie and Diane in August 1955 occurred soon after the thinning, the accompanying high winds did not appreciably affect the thinned stands—possibly because the plots are on a flat site and are surrounded by other forest stands.

BASAL-AREA AND DIAMETER GROWTH

Sample-Tree Data

Cutting every other row caused the greatest stimulation of growth among the residual sample trees—0.3 to 0.4 inch more diameter growth in thinned than in check trees in all crown classes during the 5-year period (table 1). Among the sample trees released by cutting every third row, the increased growth was 0.2 to 0.3 inch; by cutting every fourth row, 0.1 to 0.3 inch; and by cutting every fifth row, 0.0 to 0.2 inch.

Although diameter-growth increases were not markedly different among crown classes, growth increases in terms of basal area were considerably greater in the larger, dominant trees than in the smaller codominants and intermediates. Where every other row was cut, the basal-area increases were 0.0488, 0.0249, and 0.0243 square feet for the three crown classes, respectively (table 2).

In the strips left after cutting every fourth or fifth row, the interior unreleased trees showed hardly any response to thinning (tables 1 and 2).

The statistical analysis began with isolation of the important independent variables affecting diameter increment. First considered were the continuous independent variables—that is, the independent variables other than thinning treatment and crown class. These were: original (1954) stem diameter, original crown length, original stem length to base of live crown, original crown ratio (live-crown length as percent of total height, expressed as a whole number), squared values of each of the above variables, and simple interactions among them.

Table 2.—*Effect of row thinning on average basal area growth per tree, by crown classes*

Treatment, row cut	Area	Dominant trees	Codominant trees	Intermediate trees
		Square Feet	*Square Feet*	*Square Feet*
Every other row	Treated	0.1357	0.0925	0.0402
	Check	.0869	.0676	.0159
Every third row	Treated	.1144	.0798	.0317
	Check	.0962	.0697	.0184
Every fourth row	Treated: released	.0994	.0552	.0268
	Treated: unreleased	.1025	.0464	.0215
	Check	.0803	.0494	.0126
Every fifth row	Treated: released	.1105	.0687	.0243
	Treated: unreleased	.1022	.0584	.0268
	Check	.1077	.0604	.0184

Data for all sample trees in terms of the above variables were subjected to regression analysis. Original diameter, crown ratio, and their interaction proved to be most significant. The equation obtained from this analysis was:

$$\text{Diameter increment (inches)} = 0.312\ (\text{d.b.h.}) + 0.049\ (\text{crown ratio}) - 0.0043\ (\text{d.b.h.} \times \text{crown ratio}) - 2.00$$

For this equation, the standard error was 0.28, and the coefficient of multiple correlation was 0.74. The first two terms in the equation simply indicate that diameter increment is positively related to d.b.h. and crown ratio. However, the minus interaction term reveals that diameter increment tends to level off as d.b.h. and crown ratio get larger and larger.

In preparation for an overall covariance analysis, the sample tree data were divided into 7 thinning-treatment classes and 3 crown classes—a total of 21 treatment-crown class combinations. The 7 treatment classes include separate listings for released and interior trees in the every-fourth- and every-fifth-row thinnings. Of the continuous variables tested as covariates, only d.b.h. and crown ratio were important. The interaction term, which had

proved significant in the regression for all sample trees, dropped out of the picture when the data were subdivided into treatments and crown classes. The regression coefficients did not differ significantly among treatment-crown class groups. However, the elevation terms or treatment-crown class values did differ. Thus, the following equation was derived:

Diameter increment (inches) = 0.0756 (d.b.h.) + 0.0126 (crown ratio) + (treatment-crown class value)

The treatment-crown class values for the above equation were as follows:

Treatment	*Dominant trees*	*Codominant trees*	*Intermediate trees*
Thinned every other row	+0.34	+0.19	—0.08
Thinned every 3rd row	+0.24	+0.05	—0.29
Thinned every 4th row	+0.07	—0.17	—0.33
Thinned every 5th row	+0.08	—0.16	—0.45
Unreleased in thinning:			
Every 4th row	—0.01	—0.27	—0.50
Every 5th row	—0.03	—0.21	—0.58
Check trees	—0.09	—0.22	—0.53

For this equation, the standard error was 0.22 inch, and the coefficient of multiple correlation was 0.86. Note that this equation is somewhat more precise than the one developed without consideration of thinning treatment and crown class.

The treatment-crown class values indicate the relative position of the curve of diameter increment over d.b.h. and crown ratio for each combination of thinning treatment and crown class. Note that the position of the curve drops rather consistently with decreasing thinning intensity and with decreasing tree dominance. To predict diameter increment for a tree, it is only necessary to insert the appropriate d.b.h., crown ratio, and treatment-crown class value into the equation and make the necessary computations. This procedure will illustrate that the treatment-crown class values are measures of the differences among treatments and crown classes in predicted diameter increment. For example, for any given d.b.h. and crown ratio, the predicted increment of released dominant trees is 0.10 inch greater under every-other-row thinning than under every-third-row thinning: it is 0.17 inch

greater under the latter treatment than where every fourth row was removed, and so on.

Adjusted means were computed for each treatment-crown class combination. This technique eliminates the effects of initial differences among trees in d.b.h. and crown ratio. Comparisons of adjusted means among crown classes were not considered realistic because trees in the upper crown classes naturally have larger diameters and higher crown ratios than trees in the lower crown classes. However, comparisons of adjusted means among thinning treatments revealed some meaningful differences that were not evident in table 1. Of most importance, the difference in average growth of released trees between every-other-row and every-third-row treatments became 0.10 inch for dominants, 0.14 inch for codominants, and 0.21 inch for intermediates, as compared to the 0.1-, 0.2-, and 0.0-inch respective differences between means in table 1. Thus, every-other-row thinning favored the intermediate crown class more than the unadjusted means in table 1 indicate. In the unadjusted means, this effect of the more intensive thinning is obscured by differences among treatment plots in average d.b.h. and crown ratio of the intermediate trees.

An analysis of variance and orthogonal comparisons of unadjusted means were used to determine the significant differences among crown classes and treatments. The results show that:

- Diameter increment differed significantly among crown classes.
- The thinnings increased diameter increment significantly.
- Release on two sides of a tree, or every-other-row thinning, increased this increment significantly more than when trees were released on one side.
- Trees released on one side by cutting every third row grew significantly more than those released by cutting every fourth or fifth row. There was no significant difference between the last two treatments.
- The diameter increment of unreleased trees in the strips left after cutting every fourth or fifth row did not differ significantly from that of trees in the control plots.

A separate analysis indicated a significant difference between the growth of released trees from cutting every fourth or fifth row and that of trees in the control plots. All significant differences mentioned above were at the 1-percent level.

Stand Data

Stand records indicated treatment responses similar to those shown by the individual sample trees. Cutting every other row resulted in by far the greatest net gain in basal area—double that from cutting every third row (table 3). The control and the other two treatments had small net losses, that is, less basal area in 1959 than in 1954. However, their 1954 basal-area values were comparatively high—113 to 171 square feet per acre.

If mortality and the slow growth of small pines are ignored, the differences among treatments are smaller. For example, crop trees in the every-other-row cutting did grow the fastest in basal

Table 3.—*Basal areas per acre for all pines and for crop trees only, by treatments*

Treatment, row cut	All pines			Crop trees		
	1954	1959	Change	1954	1959	Change
	Sq.Ft.	*Sq.Ft.*	*Sq.Ft.*	*Sq.Ft.*	*Sq.Ft.*	*Sq.Ft.*
Every other row	76.2	89.5	+13.3	36.2	49.9	+13.7
Every third row	108.0	114.6	+ 6.6	35.1	48.0	+12.9
Every fourth row	121.7	118.9	− 2.8	38.3	47.2	+ 8.9
Every fifth row	112.8	109.2	− 3.6	42.0	50.8	+ 8.8
None (check)	171.1	169.8	− 1.3	40.2	50.0	+ 9.8

area (table 3), but were followed so closely by those in the every-third-row cutting that diameter growth computed to the nearest 1/10 inch was the same (table 4). In the other two treatments, crop trees grew somewhat more slowly than in the check area (tables 3 and 4).

Table 4.—*Average diameter of all pines and of crop trees only, by treatments*

Treatment, row cut	All pines			Crop trees		
	1954	1959	Change	1954	1959	Change
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Every other row	5.5	6.6	+1.1	6.6	7.8	+1.2
Every third row	5.6	6.5	+0.9	6.6	7.8	+1.2
Every fourth row	5.8	6.7	+0.9	6.8	7.7	+0.9
Every fifth row	5.7	6.7	+1.0	7.2	7.9	+0.7
None (check)	6.0	6.9	+0.9	7.0	7.9	+0.9

When all pines are considered, the 5-year changes in average diameter were similar in all treatments—between 0.9 and 1.1 inches (table 4). However, among crop trees, the most drastic treatments produced about 0.3 inch more diameter growth in the 5-year period than occurred in the check plot—a response comparable to that shown by the sample trees.

CROWN RATIOS

Original live-crown ratios in 1954 ranged from 39 percent (of total height) for dominants, to 35 percent for codominants, to 29 percent for intermediates. Average lengths of live crown were 17.7, 15.1, and 11.1 feet, respectively.

Crown ratios of sample trees in the check areas decreased slightly—by an average of 2 percentage points—during the 5-year study period. Crown ratios of the interior unreleased trees in the strips left after cutting every fourth or fifth row underwent practically no change during this period.

For all released sample trees collectively, crown ratios increased by an average of 2 percentage points. Increases were greater among dominant stems than among intermediates, and they were appreciably greater in the every-other-row cutting than in the other treatments. Dominants in the every-other-row treatment increased their live-crown ratio by an average of 8 points—from 37 to 45 percent. The original differences in crown ratios between

dominants and other trees became even greater during the 5-year period in all treatments because of the greater response of the dominants to release.

CROWN CLASS

Except in the every-other-row treatment, the trees underwent little change in crown class in the 5-year period other than minor shifts both up and down. However, in the every-other-row treatment, 35 percent of the trees classed as codominant in 1954 were classed as dominant in 1959.

VOLUMES AND VOLUME GROWTH

Because of initial differences in stand conditions, the volumes left after treatment did not decrease uniformly from the check plot to the heaviest thinning (table 5). The check plot, incidentally, had more volume than any of the treated ones before thinning.

Even so, the check area grew the most volume in the 5-year period, 6.8 cords per acre, followed closely by the two more heavily thinned plots. Under the two lighter thinnings, growth was 4.3 and 4.6 cords per acre.

Of course, in terms of growth percent on residual volume, the

Table 5.—*Volumes and 5-year growth per acre, by treatments*

Treatment row cut	Volume[1] per acre After thinning	5 years later	5-year growth	
	Cords	*Cords*	*Cords*	*Percent*
None	30.7	37.5	6.8	22
Every fifth row	19.9	24.2	4.3	22
Every fourth row	21.4	26.0	4.6	21
Every third row	18.5	24.8	6.3	34
Every second row	13.1	19.6	6.5	50

[1] Volumes in cords of rough wood above a 1-foot stump to a top diameter (i.b.) of 3 inches. Table values were computed using field measurements and table 3 of U. S. Dept. Agr. Misc. Pub. 50 (*6*).

two more drastic treatments gave the highest values—50 percent for the every-other-row cutting and 34 percent for the every-third-row cutting. The other two treatments and the check plot produced values of 21 or 22 percent.

Discussion

Some investigators of thinning loblolly pine or other species have already reported results comparable to those obtained in this study. For example, Staebler (*4*) found that the diameter growth of individual Douglas-firs was affected by crown class, diameter (b.h.), and degree of release. In his study the largest trees made the greatest response—much as in the present study.

Crown ratio has also proved in certain studies to have a significant relationship with diameter growth as, for example, in a study of jack pine by Stoeckeler and Olsen (*5*). In view of a recent article that condemned crown ratio as being a less valuable index than crown length (*3*), the results of the present study, in which crown ratio was found to be the better index, are particularly interesting.

Most of the questions raised earlier about the effects of row thinning have been satisfactorily answered by this study and other experience with row thinning on the Eastern Shore:

- In typical plantations, cutting every third row (or at wider intervals) does not remove too many of the best trees. Cutting every other row may, in some spots, leave an insufficient number of desirable crop trees.
- Row thinnings can be a commercial operation in areas that have a market for pulpwood. In the Pocomoke State Forest, all the plantations comparable in age to our study plantation have been row-thinned, mostly by cutting every third row, and most of this thinning has been accomplished through stumpage sales to commercial operators.
- No evidence that row thinning results in any immediate increase in wind or snow damage has appeared in our study plots or in the Pocomoke Forest plantations. However, some

damage by *Fomes annosus* is now noticeable, especially in the Pocomoke Forest. In the study plantation, fruiting bodies of *F. annosus* were found in 1961 on most of the residual trees in the thinned plots, but on very few trees in the unthinned plots.

- One question that cannot yet be answered is the effect of row thinning on the production of piling. This and other long-term effects that may develop could modify present conclusions.

Unthinned stands about 20 years old on the Eastern Shore usually are still growing at a rapid rate: in our check plot, dominants added an inch in diameter in the 5-year study period (from ages 17 to 22), and stand growth was 6.8 cords per acre. However, crown ratios were diminishing: at 17 years the ratios of even the dominant trees were dropping below the 40 percent that Chapman (*1*) recommends, and some further decline occurred during the study period. The next 5 years almost certainly will accentuate the differences between the check and the treated stands in both crown ratio and growth rate. So, unless *Fomes annosus* infection after cuttings proves to be a determining factor, dense young loblolly pine plantations on the Eastern Shore apparently should be thinned at about 20 years of age.

If the row method of thinning is chosen, we recommend removing every third row. Although cutting every other row results in greater response in diameter growth and crown development, it may leave too few desirable stems. On the other hand, cutting only every fourth or fifth row is too light a treatment; some of the residual trees are not released, and the overall benefits are considerably less than when every third row is cut.

Summary

In 1954, four thinning treatments were tried in a 17-year-old loblolly pine plantation in the Eastern Shore section of Maryland. The four treatments involved cutting all the trees in: (1) every other row, (2) every third row, (3) every fourth

row, and (4) every fifth row. Row thinning was investigated because pulpwood operators will pay a fair stumpage price for the thinnings when this method is used, whereas removal of scattered stems is not commercially feasible in such plantations.

Statistical analyses of 5-year data (1954-59) indicated that diameter increment after thinning was related to original diameter (b.h.), crown class, crown ratio, and degree of release.

Cutting every other row of trees caused the greatest stimulation of growth in diameter and basal-area increment per tree, in basal-area growth per acre, in volume-growth percent of the stand, and in crown development of the remaining trees. However, in spots this drastic treatment left an insufficient number of desirable crop trees.

Cutting every fourth or fifth row produced so little stimulation of growth that in some respects, as in diameter growth of the crop trees or in volume-growth percent of the stand, results were about the same as in untreated areas.

Consequently, for thinning plantations similar to the one that was studied, removal of every third row is recommended. While this did not stimulate growth per tree in the study plots quite as much as cutting every other row, it did increase average diameter growth by 0.2 to 0.3 inch in the 5-year period. It also favored greater crown ratios, and increased stand volume growth by 12 percent, as compared to an unthinned control.

Fruiting bodies of *Fomes annosus* were present in 1961 on many of the residual trees in the thinned plots. How serious the damage from *Fomes* infections will become in thinned plantations on the Eastern Shore is still an open question. It is possible that, because of the *Fomes* threat, the above thinning recommendation may later have to be modified.

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Silvical Characteristics of Eastern White Pine

(*Pinus strobus*)

by Robert W. Wilson Jr.
William E. McQuilkin

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RALPH W. MARQUIS, DIRECTOR

Preface

MUCH of the silvical information about our forest trees is widely scattered and sometimes difficult to find. To make this material more readily available, the U. S. Forest Service is assembling information on the silvical characteristics of the important native forest tree species of the United States. It is expected that this information will be published as a conprehensive silvics manual.

This paper presents the silvical characteristics of one species —eastern white pine. In contains the essential information that will appear in the general manual but has been written with particular reference to the species in the Northeast. Similar reports on other species have been prepared by the Northeastern Forest Experiment Station and several of the other regional experiment stations of the U. S. Forest Service.

Silvical Characteristics of Eastern White Pine

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About the Authors . . .

ROBERT W. WILSON JR. *took his Bachelor's degree at Pennsylvania State University in 1947 and his Master's at Yale in 1948. He joined the Forest Service in 1948 and for 10 years did silvicultural and forest-management research at the Northeastern Station's research unit at Laconia, N.H. In 1958 he moved to a staff position in the Division of Forest Management Research at Station headquarters in Upper Darby, Pa. Since 1961 he has been in charge of the Station's Biometrics unit at New Haven, Conn.*

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The White Pine

THE eastern white pine is at maturity the most majestic of the eastern conifers. And no other tree has played so great a role in the history of the American people. White pine was the first product exported from this country. It became a cause in the rebellion that led to our War of Independence. It gave rise to the great lumbering industry in the brawling days of the legendary Paul Bunyan, the great logging camps, and the log rafts that once choked the rivers of the East. The logging, milling, and construction industries based on white pine created towns and cities, provided livelihoods for hundreds of thousands of laborers and artisans, and made financial empires for some entrepreneurs.

The first European explorers who probed the coasts of North America were awed by the great forests of white pine that covered vast areas of the land. Trees 150 feet tall were fairly common; some have been reported as tall as 240 feet, some as large as 12 feet in diameter.

The exploitation of this forest wealth began even before the land was peopled. In 1605 Captain George Weymouth of the British royal navy, after exploring the coast of Maine, carried home with him samples of this magnificent timber—and with a particular purpose in mind: shipmasts. England, for all her naval power, had to import pine from the Baltic countries and piece it together into masts. So here was a kind of timber that the British wanted badly.

Captain Weymouth also took white pine seed home with him. Established in England, white pine became known there as Weymouth pine. In our country the species has been called eastern white pine, northern white pine, northern pine, soft pine, pumpkin pine, and simply white pine.

The first colonists were quick to make use of this forest resource. The first sawmill in America, near the present site of Berwick, Maine, was set up in 1623—to saw white pine. By 1700 the British were so concerned over the supply of white pine

mast trees that they tried to reserve them. Pines 24 inches or more in diameter in the accessible coastal region were marked with the King's Broad Arrow (fig. 1), and severe penalties were imposed on any who cut them. The colonists—in Maine and New Hampshire at least—were as aroused over this as other colonies were over the tax laws, and there was much bootleg cutting of these best trees. When the trouble with England came to a head, the lumbermen almost to a man went to the patriot side.

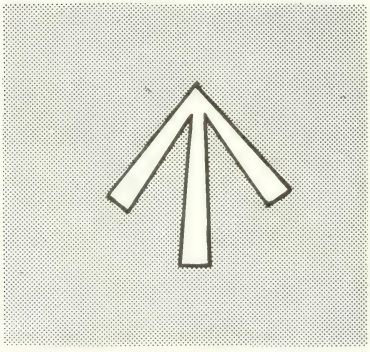

Figure 1.—The King's Broad Arrow, used to mark white pine mast trees reserved for the royal navy, helped to stir New England colonists to rebellion.

From its colonial beginning, the lumbering industry grew steadily, and became one of the mainstays of the Northeastern economy. Fleets of ships were built to carry white pine lumber all over the world. The tree was so important to the people of Maine that they made it their State Tree. As the better timber along the coastal waterways was cut, the industry moved westward, through New England, New York, and Pennsylvania, and then farther westward into the Lake States. When the sources of white pine dwindled in the Lake States (about 1910), the big lumbering companies moved on to other species and other regions.

Until relatively recent times, white pine was the pre-eminent commercial species in the forests of eastern North America. And for good reason: for white pine is the most generally useful wood that this country has had. The wood is light, and for its lightness relatively strong; it is stable, attractive, and easily worked. The wonderfully clear wood of virgin old-growth white pine was so easily carved that it was called pumpkin pine—and found its way

into the graceful doorways of New England houses, ships' figureheads, and cigar-store Indians.

Even to merely list the products made of white pine would require several pages. It was for a long time the universal building material in the northern states from the Atlantic to the Rockies. Modest dwellings and stately mansions, barns, schools, churches, hotels, commercial structures in infinite variety—all were commonly built of white pine. White pine was used to build the famous covered bridges of the East—and to make match sticks.

Though now eclipsed in lumber volume production by other species, white pine still is in high demand because of its unparallelled qualities. The natural beauty of the tree itself excites the admiration of all who love trees. The many fine qualities of the tree and its wood have held a strong popular interest since the days when Europeans first landed in this country. And no doubt the white pine will continue for a long time to hold a special place in the affections of the American people.

Habitat Conditions

White pine ranges across southern Canada from Manitoba to Newfoundland, throughout our Northern and Eastern States from Minnesota and northeastern Iowa to the Atlantic Coast, and southward along the Appalachians to northern Georgia and Alabama (fig. 2).

CLIMATIC

The climate over the range of white pine is cool and humid. The distribution of white pine coincides reasonably well with that portion of eastern North America where the July temperature averages between 62 and 72° F. *(94)*. Annual precipitation varies from about 20 inches in northern Minnesota to about 80 inches in northwestern Georgia. In the area surrounding the Great Lakes about two-thirds of the precipitation occurs during the warm season—April to September. Elsewhere, half of the precipitation occurs during the warm season. The length of the growing season varies from 100 to 200 days *(94)*.

Over the range of white pine precipitation is about 1 to 1½ times the evaporation from shaded free-water surfaces *(92)*. According to Thornthwaite *(88)*, average annual potential evapotranspiration is between 17 and 28 inches, of which 56 to 68 percent occurs in the warm season. There is a moisture surplus in all seasons.

SOILS

Soils within the natural range of white pine are derived from granites, gneisses, schists, standstones, and—less commonly—from phyllites, slates, shales, and limestones. Since most of the area was covered by the Wisconsin glaciation, the soils are young, relatively coarse-textured, and have weakly developed profiles *(93, 96)*. In New England some of the uplands have a cap of silty material over the glacial till. From central Pennsylvania southward and in southwestern Wisconsin the soils are much older, generally are finer textured, and have well-developed profiles. In Canada, white pine occurs more commonly on glacio-fluvial and aeolian materials than on tills and lacustrine deposits *(39)*.

White pine has grown on practically all the soils within its range *(25)*. It has been most closely associated with somewhat excessively drained and well drained sandy soils. Such soils are good enough to permit fair growth rates of white pine but not good enough for strong competition from aggressive hardwoods *(39)*. White pine occurs also on loams and silty soils with either good or impeded drainage when there is no hardwood competition during the establishment period—as on old fields and pastures, and on burns and blow-downs. However, these richer soils are usually occupied by hardwoods, with some white pine in mixtures. Less commonly white pine has been found on clayey soils and on poorly drained or very poorly drained soils with surface mounds *(2, 8, 12, 13, 40, 49, 98)*. The species commonly is associated with a moderate degree of soil podsolization *(39)*.

As availability of soil moisture and soil nutrients increases, the quality of a soil for the growth of white pine tends to increase. On the basis of site studies at different places over the species' range, researchers have expressed this relationship indirectly by various combinations of soil and topographic characteristics—

texture and thickness of the A and B horizons, depth and permeability of the underlying rock or pan, depth to water table, natural drainage class, topographic position, slope percent, and aspect *(20, 26, 42, 49, 55, 74, 84, 98, 103)*.

The form and distribution of the white pine root system varies with some of these same soil characteristics. The normal root system has only the vestige of a tap root. Several (usually three to five) large roots spread outward and downward in the soil, giving the tree a firm anchor under most conditions *(25)*. From a zone below the root collar a mass of smaller lateral roots spreads horizontally in all directions, branching ultimately into the so-called feeding roots *(27, 86)*.

Large lateral roots reach greater depths in deep soils than in soils that are relatively shallow to an impenetrable layer. In deep coarse-textured soils "sinker roots", which branch from the laterals and grow straight down, seem to be fairly common; but they are seldom found in other soils. Most of the feeding roots are concentrated in the upper part of the soil material—the H, A, and B·

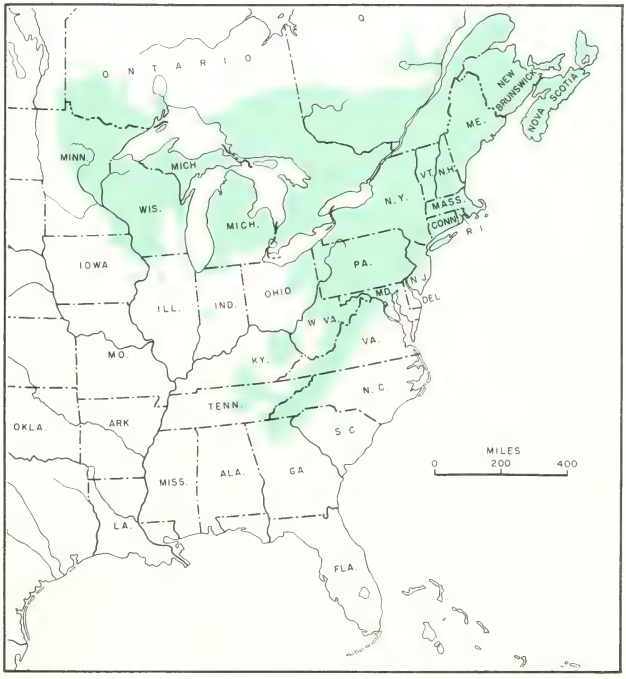

Figure 2.—The natural range of eastern white pine.

horizons *(27, 44)*. Such soil properties as fine texture, good structure and consistency, relatively high available moisture at field capacity, high total exchange capacity, high content of exchangeable bases, high total nitrogen, and high organic matter—in short, the properties that make up soil fertility—all favor the concentration of fine feeding roots.

PHYSIOGRAPHIC

In New England and New York white pine generally grows at elevations between sea level and 1,500 feet, or occasionally higher. In Pennsylvania the range is from 500 to 2,000 feet *(2)*. In the southern Appalachians white pine occurs in a band along the mountains between 1,200 and 3,500 feet above sea level, occasionally reaching 4,000 feet *(3, 6, 14)*. In Pennsylvania and the southern Appalachians most white pine is found on northerly aspects, in coves, and on stream bottoms. Elsewhere within its climatic range, occurrence is seldom restricted by altitude, aspect, and slope position.

BIOTIC

White pine is distributed naturally through part or all of six forest regions *(79)*. It is a major component of the white pine-northern red oak, white ash, white pine, and white pine-hemlock types (fig. 3) and is an element in 15 others. It may be associated with other conifers, including hemlock *(Tsuga canadensis)*, red spruce *(Picea rubens)*, white spruce *(Picea glauca)*, balsam fir *(Abies balsamea)*, northern white-cedar *(Thuja occidentalis)*, pitch pine *(Pinus rigida)*, jack pine, *(Pinus banksiana)*, red pine *(Pinus resinosa)*, and shortleaf pine *(Pinus echinata)*. Common hardwood associates are gray birch *(Betula populifolia)*, paper birch *(Betula papyrifera)*, sweet birch *(Betula lenta)*, yellow birch *(Betula allegheniensis)*, American beech *(Fagus grandifolia)*, sugar maple *(Acer saccharum)*, red maple *(Acer rubrum)*, white ash *(Fraxinus americana)*, American basswood *(Tilia americana)*, bigtooth aspen *(Populus grandidentata)*, quaking aspen *(Populus tremuloides)*, pin cherry *(Prunus pensylvanica)*, black cherry *(Prunus serotina)* northern red oak *(Quercus rubra)*, black oak

Figure 3.—A 100-year-old stand of mixed white pine and hemlock in New York.

(Quercus velutina), white oak *(Quercus alba),* chestnut oak *(Quercus prinus),* and the hickories *(Carya spp.).*

The value of ground vegetation as indicators of white pine sites is somewhat clouded by the different vegetation types recognized by various authors *(29, 33, 34, 85),* and by the effect of catastrophic events on the vegetation types. However, on dry sites of low productivity the vegetation type is usually composed mainly of one or more species of the genera *Vaccinium, Gaultheria, Diervilla, Comptonia, Pteridium, Lycopodium, Andropogon,* and *Cladonia.* The moist, rich sites of high productivity support a ground vegetation made up principally of several species in the genera *Oxalis, Mitchella, Arisaema, Aralia,* and *Dennstaedtia.* Intermediate sites have ground vegetation containing varying proportions of the above, along with *Cornus, Maianthemum,* and *Pteridium.*

Life History

SEEDING HABITS

Flowering and Fruiting

In the vicinity of Ithaca, New York (latitude 42° north), new flowers are first noticeable about May 1, and pollination takes place about June 1; but fertilization does not occur until 13 months later *(22).* The cones (fig. 4) mature the following fall—two growing seasons after flower initiation. White pine cones ripen comparatively early in the season; in central Massachusetts, for instance, they are ripe by late August *(61).* Occasionally some cones mature in which fertilization has not taken place *(63).*

Trees may start to bear female flowers at 5 to 10 years of age *(71, 72).* In the Philadelphia area, quantity production of female flowers does not begin until the trees are about 20 feet tall. At that size 200 to 300 flowers may be produced in one year; the number is only a little greater on larger or older trees. Few or no male flowers appear during the early flowering years. Femaleness persists even among older trees 1 to 2 feet in diameter, although trees of this size do produce small to moderate amounts of pollen *(101).*

Figure 4.—Mature cones of white pine, on a down tree. This was an unusually good seed crop.

Casual observations in southwestern Maine and New Hampshire suggest that flowering is heavier in that area. Trees 50 or more years old have often yielded well in excess of 400 cones. In some years such trees bear male flowers so profusely that heavy clouds of pollen are formed.

The pattern of flowering in white pine is uncertain. In the Philadelphia area the better-flowering trees tend to produce about the same number of female flowers every year, with some exceptions; male flowers, however, do not appear annually *(101)*.

Seed Production and Dissemination

Good seed years are reported to occur every 3 to 5 years, and some seed is produced in most intervening years *(95)*. However, at the Massabesic Experimental Forest in southern Maine and at other New England locations only one light seed crop has matured in the 15-year period 1948-62, and virtually no seed was produced in the other 14 years. The major cause for these failures

probably has been the white pine cone beetle *(Conopthorus coniperda* (Schw.)). During recent years entire crops of 1-year-old cones have been weeviled by this insect and have dropped to the ground by midsummer of the second growing season. In breeding work with both unbagged and continuously bagged white pine flowers, Wright and Gabriel *(102)* concluded that the heavy mortality among unbagged flowers was caused mainly by this insect, although they also recognized squirrels and a lepidopteran coneworm as minor causes of mortality.

Optimum seedbearing age is between 50 and 150 years *(95)*. In a comprehensive study of white pine seed production in Germany it was found that a 90-year-old stand produced 78 pounds of seed per acre; a comparable 60-year-old stand produced only one-fifth as much. In these stands dominant trees produced twice as many cones as codominant trees *(52)*.

Most of the seed produced is dispersed within the month after cone maturity *(95)*. The seed will travel at least 200 feet within a white pine stand *(46)* and more than 700 feet in the open *(99)*.

There are about 2 pounds of cleaned seed in 100 pounds of fresh cones, and the seeds number 27,000 per pound—the range is from 20,000 to 53,000 *(95)*. In a study of 250 different parents from all parts of the white pine range the number of good seeds per sound cone varied from 0 to 73[1]. The poorest seed sets were found in stands at the extremes of the species range.

VEGETATIVE REPRODUCTION

White pine does not reproduce vegetatively under natural conditions. However, small cuttings of the last season's twigs taken in late winter from trees 2 to 6 years old will root rather readily *(17, 18)*. Within 9 years outplanted cuttings have developed the same form and size as seedlings, with a root system approaching that of seedlings *(65)*.

Side grafts of scions on 3- or 4-year-old white pine stocks appear to be a more reliable method of vegetative propagation than rooted cuttings *(1, 35)*.

[1] Wright, Jonathan W. Unpublished office report, Northeastern Forest Experiment Station, Upper Darby, Pa.

SEEDLING DEVELOPMENT

Establishment

Germination of white pine seed is highly variable; laboratory germinative capacities from 0 to 96 percent (average, 64 percent) have been reported *(95)*. Some of the variation is related to seed weight—heavy seeds germinate better than light seeds; some is related to seed origin—seeds from some mother trees germinate better than those from others (83). Embryo dormancy is general; it can be broken by exposure to moisture at temperatures of 40 to 50°F. for 30 to 60 days *(95)*.

Seedbed requirements for white pine regeneration have been concisely stated by Smith *(78)*:

> The variable influence of seedbed conditions on germination and early survival of white pine seedlings is confined almost entirely to areas exposed to direct sunlight. These variations are due chiefly to differences in the efficiency with which seedbed materials dissipate heat received from the sun. Seedbeds which lose heat slowly attain high surface temperatures. Extreme dessication associated with these temperatures causes significant reductions in germination. Heat injury also kills many seedlings on such seedbeds.

Under the condition of full exposure to sunlight, the favorable seedbeds are moist mineral soil, polytrichum moss, or a short-grass cover of light to medium density. Dry mineral soil, pine litter, lichen, and very thin or very thick grass covers are unfavorable *(78, 82, 91)*.

Unfavorable seedbed conditions can be corrected by scarification or can be overcome by shade. However, dense low shade such as that cast by slash piles or hardwood brush is inimical to later survival, and the shade from young stands of gray birch or pitch pine will reduce white pine growth in the later stages. Overstory shade resulting from a form of shelterwood cutting provides good protection during the early stages of growth and is least damaging to later stages *(78, 82)*.

Early Growth

After the establishment period, light intensity becomes critical to the survival and growth of white pine seedlings. At light intensities of less than 10 to 13 percent of full sunlight, survival is uniformly

poor; at least 20 percent of full sunlight seems to be required to keep the seedlings alive *(76, 90)*. As light intensity increases above this point, growth increases proportionately up to full sunlight unless some other condition becomes limiting *(56, 57, 59, 76, 78)*.

Figure 5.—Eastern white pine seedlings growing successfully under the partial shelter of parent seed trees.

Although young white pine seedlings can survive for several weeks in soils with moisture below the wilting coefficient *(78)*, growth at a given light intensity is best in the absence of root competition. Growth is better when only an overstory offers root competition than when both an understory and an overstory are competing *(76)*.

Either an excess or a deficiency of nutrients will also limit growth. In greenhouse and nursery trials it has been shown that the optimum supply of nitrogen is 300 p.p.m. (parts per million); of phosphorus, 350 p.p.m.; of potassium, 150 p.p.m.; and of calcium, 200 p.p.m. *(56, 57, 58)*. Definite symptoms of nutrient deficiency seldom occur in white pine growing under field conditions; however, in certain areas of low-nutrient outwash quartz sands, such symptoms may appear, particularly in plantations *(39)*. Potassium commonly is the most critically deficient element in these areas.

Seed weight and seed source affect early growth *(83)*. The largest seedlings generally come from the heaviest seed; the correlation decreases after the first year but is still significant at the end of the third year. Growth differences attributed to different mother trees continue unabated through the third year.

Early growth of white pine is comparatively slow. Open-grown trees are about 5 inches high when 3 years old. They are 12 inches high when 5 years old and usually reach 4.5 feet in height only after 8 to 10 years' growth. After that, height growth may be rapid (fig. 5). Between the tenth and the twentieth years open-grown dominant trees have grown as much at 4.5 feet in height in a single year. Annual increments of 3 feet are not uncommon, but average height growth of dominant trees during this period is about 16 inches annually.

SAPLING STAGE TO MATURITY

By the time dominant trees on medium-quality sites are between 20 and 30 years of age, height growth is about 20 inches annually (fig. 6). At 50 years current annual height growth drops to 14 inches and at 100 years to 5 inches *(25)*. A minimum rate of 2 to 3 inches is reached at about 165 years of age *(81)*; this rate is apparently sustained for the life of the tree.

Figure 6.—A natural stand of sapling white pines about 30-35 years old. This stand had about 3,200 pine stems per acre.

Diameter growth is subject to wide variation with differences in stand density, site quality, and the age and development of individual trees. It may be as rapid as 1 inch per year or as slow as 1 inch in 40 years. Dominant trees will ordinarily grow at the rate of 5 to 10 rings per diameter-inch to an age of 250 years *(81)*. In fully stocked stands on average sites, average tree diameter increases at a nearly uniform rate of 1 inch every 5 to 7 years *(25, 81)*.

Periodic annual cubic-foot yield in fully stocked unmanaged stands culminates at about 40 years of age (190 cubic feet per

Figure 7.—Mature white pines in Maine. A long-lived tree, white pine may exceed 450 years in age.

Figure 8.—The bark characteristic of mature white pine. In young trees the bark is smooth and glossy, and a characteristic green-black color.

acre) on average sites *(25)*, while mean annual yield is greatest at about 60 years (140 cubic feet per acre). (See table 1.).

White pine is a long-lived tree (fig. 7 and fig. 8). It commonly reaches 300 years of age when undisturbed; maximum age may exceed 450 years *(81)*. It is capable of attaining very large size. One white pine cut in Lycoming County, Pennsylvania, in 1899 was reported to be 12 feet in diameter at the butt and 200 feet tall *(69)*. Trees 40 inches in diameter and 150 feet tall were not unusual in the virgin forests of Pennsylvania, Michigan, and New England *(81)*.

Table 1.—*Estimated yield of fully stocked pure white pine stands*[1]

(In thousands of board feet, International ¼-inch rule, trees 7 inches d.b.h. and larger)

Age	Site index			
(years)	45	55	65	75
50	8	18	28	38
100	40	52	68	78

[1] Compiled from Frothingham (*25*), Gevorkiantz and Zon (*29*), McCormack (*49*), Pinchot and Graves (*68*), and Tarbox and Reed (*87*).

Enemies

Many destructive agents attack eastern white pine. Some kill the tree. Others, though they do not kill, do limit the regeneration or growth of the species or affect the quality of the tree or its wood.

The white-pine weevil (*Pissodes strobi*) is a native insect that attacks and kills the terminal shoots of eastern white pines (fig. 9). The tree is seldom killed unless it is very small; usually one or two of the lateral branches from the highest living whorl turn upward to become new terminal shoots. However, this usually produces a crook in the bole, which ultimately affects log quality; sometimes it causes a forked tree (fig. 10). This type of injury also causes loss in stem length *(47)*. Sometimes 2 or even 3 years' growth is affected. Weevil damage generally is less severe among trees growing as an understory than among trees grown in the open, but growth of course is reduced in understory situations.

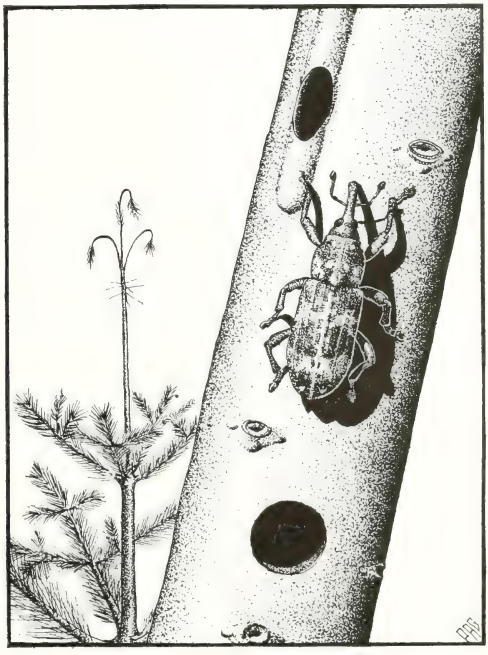

Figure 9.—The white-pine weevil is the most serious insect enemy of white pine. It attacks and kills the terminal shoots.

Figure 10.—Damage done by the white-pine weevil. Though the weevil seldom kills the tree, it causes crooks and forks that spoil the timber quality.

The Pales weevil (*Hylobius pales*) is an insect that often attacks white pine seedlings in areas where pine timber has been cut recently. These weevils breed in the fresh stumps and slash of pine cuttings; and they attack nearby live seedlings, girdling them and usually killing them. Most of the damage occurs during the first 3 years after a cutting, and among seedlings less than 5 years old *(5, 10, 24)*.

White pine blister rust, a disease caused by an introduced fungus (*Cronartium ribicola*), has proved to be highly virulent throughout the range of white pine (fig. 11). The fungus uses Ribes plants (currants and gooseberries) as an alternate host, and control is effected by eradicating the Ribes. White pine trees are susceptible to this disease from seedling stage to maturity. Where it is not controlled, blister rust can cause severe losses both in regeneration and in immature timber stands *(7, 54)*.

Red ring rot caused by the fungus *Fomes pini* is the most important rot that infects white pines. Losses are greater in older trees but do not build up rapidly *(32, 97)*. Decay is restricted to the heartwood, to which the disease gains entrance through

Figure 11.—Blister rust, a fungus disease that uses Ribes plants (currants and gooseberries) as an alternate host, can cause severe losses in immature stands.

wounds, dead limbs, or weeviled tips *(32, 64)*. *Stereum sanguinolentum*, a wound parasite, is probably the third most destructive fungus associated with white pine. It often gains entrance to trees through pruning wounds *(41, 77)*.

Polyporus schweinitzii is one of the most common and destructive root rots *(7)*. And a root rot caused by *Fomes annosus* is found particularly in plantations of white pines (and other conifers). Thinnings increase the incidence of this disease *(37, 39, 60)*; the fungus readily infects the stumps, spreads through the root system, and then infects nearby trees through root contacts.

Fire is also an enemy. Because the bark on exposed roots and the younger portion of the stems in second-growth white pine stands is thin, fire resistance in such stands is low. Losses are invariably heavy after a fire, and fire-caused mortality continues for several years *(48)*. Old trees have thicker bark and are at least moderately resistant to fire.

White pine is relatively windfirm if permitted full development, but in dense stands wind damage may be expected from the occasional severe storm, particularly after a recent partial cutting *(15)*. Wind-deformed trees are subject to later compression failures in the bole *(51)*.

In some localities and in some years deer, rabbits and hares, squirrels, mice, porcupines, the pine grosbeak, and various sawflies will cause extensive damage to needles, buds, twigs, or bark of seedlings and small saplings. The damage done by these agents usually is not fatal, but reductions in growth and deformation of the stem frequently result.

Reaction to Competition

The white pine has been classified as intermediate in tolerance *(4, 39)*. It will endure moderate shade and makes moderate demands on the soil. In competition with light-foliaged species like the birches and pitch pine, white pine will sooner or later gain dominance in the stand—in most cases *(80, 82, 89)*. However, against the stronger competition of such species as the aspens, oaks, and maples, white pine usually fails to gain a place in the

upper canopy and eventually dies *(23, 28, 43, 45, 50, 104)*.

In the seedling stage white pine is very susceptible to competition because its capacity for rapid height growth is low in relation to that of most of its associates. If the white pine survives to the sapling stage, its potential rate of height growth increases and its ability to compete is greatly improved *(21, 80)*.

At either stage, the amount of response to release depends primarily upon how strong the competition has been and how long the pine has been in a subordinate position. In general, pines less than 30 years old with at least one-third of their height in live crown will respond well. But response declines proportionately with increasing age and decreasing crown length.

Opinion on the ecological status of white pine is varied *(9, 30, 31, 62)*. However, it is clear that white pine may function as a pioneer, as exemplified by its role as the old-field pine of New England. It may function as a physiographic climax on the dryer, sandier soils. It may function as a long-lived intermediate; and it is a component of the climatic climax forest throughout its range.

Pure stands of white pine almost never stagnate. Because of variations in inherent vigor, and in age of the trees in the stand, and in the microsites they occupy, good differentiation into crown and diameter classes practically always occurs. The expression of dominance is best on the better sites, at the greater stand densities, and in natural stands as compared to plantations *(16)*.

Trees in pure second-growth stands of white pine are noted for their limbiness. In such stands the limbs live for about 15 years and persist on the trunk for more than 25 years after they die. In the first 16-foot log of these trees there is an average of about 60 limbs *(66)*.

Racial Variation

The existence of geographic races or local ecotypes in white pine has not been established; however, there appears to be some genetic variation in growth rate. In seed-source tests at the Harvard Forest with seedlings of different geographic origins, growth was best among the local sources: growth decreased in clinal fashion with

increasing distance of the seed source from the test locality *(67)*. And in a range-wide provenance test of white pine recently begun by the Northeastern Forest Experiment Station, distinct differences among seedlings of different provenances showed up in the nursery *(75)*.

Casual observations have indicated that there is geographic variation in growth rate, branchiness, drought resistance, and recovery from weevil damage between the southern Appalachians and Canada (36). Genetic variation in blister rust resistance between individual trees has been established *(38, 53, 73)*. Rehder *(70)* lists five horticultural varieties of white pine, and a naturally occurring dwarf form has been described *(11)*.

White pine will cross rather easily with most of the other 5-needle pines in the series *Strobi*. In fact, nearly all of the species in this series will cross with each other. This implies that the differentiation of these species has come about more from geographic separation than through genetic processes *(19, 100)*.

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timber management and economic analysis a case study

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timber management and economic analysis

a case study

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Introduction

IN THE economics of forestry, one of the major subject areas for research is timber production. During the past few years a number of economic analyses have dealt with this subject. For example, Buckman and Lundgren (1961), King, Stoltenberg, and Marty (1960), Lundgren (1961), Marty and Allison (1960), McMahon (1961), and Wikstrom and Wellner (1961) have made economic analyses of timber-production problems.

In their purposes these analyses differ somewhat, yet they all have much in common. In broad terms they have two interrelated objectives. First, they are designed to determine the relationship between benefits and costs for various timber-management opportunities, thus guiding timber-management funds toward those opportunities that promise the largest benefits relative to costs. Second, they may also be designed to identify the breaking point between those opportunities that are justified and those that are not. Identification of this breaking point may aid in the determination of budgets. In short, these analyses serve to arrange timber-management opportunities into a scale of priority, and they may also serve to identify the point on this scale beyond which management should not try to go.

Have these analyses reached their mark? In what kinds of timber-management decisions have they been useful? Where, specifically, have they fallen short? Can we define both the usefulness and limitations of economic analyses as a guide to timber management?

The usefulness and limitations of economic analysis for this purpose have been discussed in a number of publications. Stoltenberg (1956), Stoltenberg, Marty, and Webster (1961), Newport (1962), and Webster, Marty, and Skok[1] emphasized the usefulness of such analysis. Dowdle (1962) and Marty[2] discussed limitations as well as usefulness. These investigators

[1] Webster, Henry H., Robert J. Marty, and Richard A. Skok. FORESTRY PRACTICE, BIOLOGICAL RESEARCH, AND ECONOMIC ANALYSIS. Article submitted to Journal of Forestry, 1962.

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pointed out that economic analysis is a powerful device for viewing timber management from the viewpoint of people and their objectives; for comparing opportunities (i.e., alternative courses of action) as means of achieving these objectives; and for pulling together many different kinds of information to make these comparisons. They also pointed out that economic analysis is a somewhat less-than-perfect device since less-than-perfect information must be used.

These articles were general in the sense that they discussed economic analysis on a conceptual level. They did not attempt to directly trace the usefulness and limitations of particular analyses in terms of decisions made in particular geographic areas, or by particular forest land-management agencies.

Attempts to trace directly the usefulness and limitations of particular economic analyses would be valuable, as a pragmatic approach. Such an approach would lend substance to conceptual appraisals of the usefulness and limitations of economic analysis. Distinctions between theory and practice are much overworked, and often false. Nevertheless such an approach would provide a more practical view. And a more practical view might help several groups.

Suppose the usefulness and limitations of a number of economic analyses were traced. This might help forest managers to interpret the results of other economic analyses of timber-management opportunities. They would have a better frame of reference both for formulating their problems and for asking "Where and how might these analyses be useful to me?" A more practical view might also help researchers to direct their work toward those timber-management decisions where economic analysis can make a major contribution. And finally, it might help many, particularly students, to understand the relationship between forest management and forestry research, particularly research in forest economics.

This paper is an attempt to trace the usefulness and limitations of economic analysis as a guide to timber management. It builds upon an earlier analysis of major timber-management opportunities in Pennsylvania (Webster 1960), applying the results

to a particular area in the State. It attempts to view the analysis through the eyes of a perceptive forest manager, asking where and how this analysis has been useful and where and how has it fallen short.

This is a report on a case study. It deals with a particular economic analysis applied to a particular situation. It is in no sense a definitive treatment of the usefulness and limitations of economic analysis as a guide to timber management. Definitive treatment would require many additional cases involving other analyses directed toward other geographic areas, other product objectives, and decisions involving opportunities other than stand improvement. Nevertheless this case is a first step in a pragmatic appraisal of economic analysis as a guide to timber management.

The Management Situation

The management unit considered is the Elk State Forest in Pennsylvania, which is administered by the Pennsylvania Department of Forests and Waters as part of the Department's Administrative District 13. Its management group includes the District Forester assigned to District 13 and the Chiefs of the Divisions of State Forest Management and Forest Advisory Services in the headquarters of the Department of Forests and Waters. They jointly make management decisions, which are then carried out under the supervision of the District Forester.

The Elk State Forest (fig. 1) is located in north-central Pennsylvania. District 13, of which the Elk State Forest is a part, includes portions of Cameron, Elk, Potter, Clinton, and McKean Counties. This is a predominantly rural area, containing several towns of 5,000 to 10,000 population, but none larger. It is extensively forested: the 5 counties contain some 2.3 million acres of commercial forest land out of a total acreage of 2.7 million acres. Some 35 to 40 percent of the commercial forest land here is publicly owned (U. S. Forest Service 1958). The Allegheny National Forest is located in this general area, as are

several State Forests and areas of State Game land. Industrial holdings are also large.

A variety of market outlets for timber are found here. According to the most recent tally, some 85 sawmills operate in the 5-county area (Pa. Dept. Forests and Waters 1960). A dozen of these mills produced more than 1 million board feet of lumber each in 1960. Two large pulp mills obtain part of their wood supplies from this area. In addition, there are outlets for veneer logs and for material suitable for handles, baseball bats, and a variety of other products. Sawtimber-size timber is readily saleable here. But pulpwood-size material is less saleable because so much of it is available in relation to current use.

The Elk State Forest itself is an area of 187,000 acres. Most of it is relatively undeveloped. Some 6,000 acres are in developed parks, roads, and streams. Another 17,000 acres have been leased as a special industrial site.

The Forest contains some 287 million board feet of sawtimber and some 142 million cubic feet of additional timber in trees of less than sawtimber size. It also contains three rather highly developed recreational areas, as well as a number of additional areas that might be developed for recreational purposes at some time in the future.

Timber management on the Forest has been undertaken rather recently. A timber-management plan for the Forest was completed in 1954, and accomplishments since then have been sig-

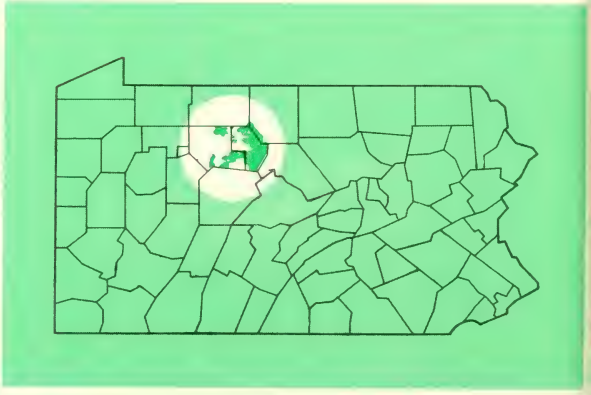

Figure 1.—Elk State Forest in north-central Pennsylvania, where a case study was made through economic analysis of timber-management opportunities.

nificant. Nearly 13 million board feet of sawtimber and some 6,000 cords of smaller material have been harvested. At the same time, many low-value trees have been removed to upgrade the forest. Receipts have totaled $440,000.

Objectives

The objectives of the Pennsylvania Department of Forests and Waters (1955) in managing the Elk State Forest have been stated as follows:

- To produce the greatest possible sustained supply of timber products.
- To improve species composition and quality of existing stands and provide for adequate residual growing stock as well as reduce the damage caused by insects and diseases.
- To regulate the cutting of timber so that the supply and flow of products from the Forest will be constant and adequate. This will tend to stabilize wood-using industries and the employment and communities dependent upon them.
- To develop and preserve the recreational values of the Forest.
- To protect the watersheds from erosion and obtain from them the maximum yields of usable water.
- To harvest timber in such a way that an adequate, uniform supply of wildlife food and cover is produced.

An economist might phrase it in slightly different terms. For example, he might place greater emphasis on minimum-cost production of various forest products. He might also make more explicit provision varying rates of production over time in response to changes in demand. And he would probably discuss the conflicts that are likely to develop as a result of attempts to simultaneously produce several forest products.

Language differences aside, this statement clearly establishes that the Department of Forests and Waters is interested in producing a variety of forest products on the Elk State Forest. Timber, water, wildlife, and recreational services are specifically mentioned.

Elsewhere in the management plan for the Elk State Forest it is established that management for production of these products is still in an early stage. At this stage, relationships between these products are more nearly complementary (or at most neutral), not competitive. For example, production of recreational services reduces opportunities for timber production on only a few carefully delineated areas. Therefore, production of the various products can be treated separately to some degree in terms of many decisions.

Specific guidelines to decisions logically follow statements of objectives. The Department of Forests and Waters has guidelines that are operationally useful although not explicitly stated in the plan. It is clear that the necessity of choosing among alternative courses of action within a fixed budget is well appreciated, as is the merit of choosing the most productive courses of action first.

Efficiency in producing additional timber values is clearly one of the Department's objectives. They intend to produce additional timber values at minimum cost; that is, to obtain the greatest pos-

Table 1. — ***Land cover and use classifications, Elk State Forest***

Land classification	Area
	Thousand Acres
Poletimber	139
Small sawtimber	17
Large and medium sawtimber	2
Saplings	4
Plantations, plantable areas, etc.	1
Recreation areas	5
Special industrial site lease	17
Roads	2
Total area	187

Source: Pa. Dept. Forests and Waters. FOREST MANAGEMENT PLAN FOR THE ELK STATE FOREST, 1955.

sible value response from funds invested in timber management.

Obviously this is not the Department's only objective. At the risk of oversimplifying, we can list at least three additional objectives: (1) to produce forest products other than timber in an efficient manner; (2) to keep the complexities of management to a tolerable level; and (3) to maintain satisfactory relations with legislators, other governmental agencies, and the citizenry of Pennsylvania.

The interrelationships between these objectives have not been specified. The Department (like nearly all agencies and firms) has not stated how much of one objective it would give up to move one degree nearer to achieving another.

Opportunities

Forest management for production of additional timber values on the Elk State Forest might include a variety of activities. Four major activities might be: (1) harvesting mature timber; (2) protecting timber stands from fire, insects, and diseases; (3) establishing new stands both in areas presently occupied by commercially valuable timber and in open areas, and in areas occupied by brush and low-value timber; and (4) management in existing immature stands, including both type conversion and management within the context of a given forest type.

Both the timber resource and the nature of going programs influence the decisions now faced in managing the Elk State Forest. Special measures for protection of timber stands are carried out under special plans. These activities, particularly fire protection, are generally believed to be operating in a reasonably satisfactory manner. Therefore they can be assumed to continue at present levels and need not be explicitly considered.

The timber resource is concentrated in a relatively few stand classifications. Poletimber stands occupy the bulk of the area, well over 80 percent. Small sawtimber stands (average d.b.h. 12 to 15 inches) occupy most of the remainder (table 1). Though harvesting mature sawtimber is certainly a first-priority activity, this large area in poletimber and small sawtimber constitutes a

major management opportunity. Management of these stands could greatly influence the kind of timber that can be harvested from the Elk State Forest in the future. Thus some of the major opportunities are in management of existing immature stands.

These opportunities can be defined further in respect to the composition of poletimber and sawtimber stands. The Elk State Forest is in hardwood country. Hardwood types occupy virtually all of the 156,000 acres in poletimber and small sawtimber (table 2); and more than 90 percent of the timber volume on the Forest is in hardwood species (table 3). The area is divided about equally between oak and northern hardwood stands. Softwood types and mixed types (the latter particularly suitable for type conversion) occupy extremely limited areas.

Table 2. — *Forest types on Elk State Forest*

Forest type	Area
	Thousand acres
Hardwood types:	
Oak	80
Northern hardwood	67
Aspen	7
Mixed types:	
Oak-hard pine	1
Softwood types:	
White pine hemlock	1
Total area in poletimber and small sawtimber stands	156

Source: Pa. Dept. Forests and Waters. FOREST MANAGEMENT PLAN FOR THE ELK STATE FOREST, 1955.

Three principal management practices might be suitable in the oak and northern hardwood poletimber and small sawtimber. (1) Thining, skillfully applied, would improve timber quality and species composition and would hasten production of mature timber in virtually all of these stands. In some stands, thinning

might reduce the oak component in favor of northern hardwood species. (2) Release might also be a possibility in some of the younger, lower-quality oak poletimber stands. A small number of these oak stands have understories of white pine that could be released. (3) Finally, complete type conversion from hardwood to softwood would be a possibility in some of the poorest oak

Table 3. — *Timber volumes on Elk State Forest*

Species group	Sawtimber volume	Additional poletimber volume
	Million bd. ft.	*Million cu. ft.*
Hardwoods	263	141
Softwoods	24	1
All species	287	142

Source: Pa. Dept. Forests and Waters. FOREST MANAGEMENT PLAN FOR THE ELK STATE FOREST, 1955.

stands. This would involve killing the oaks and then planting white spruce or larch, species generally immune to deer browsing.

These statements concerning practices that would increase timber values help to define the opportunities that are available. They do not indicate which opportunities should be undertaken. To undertake them all would be simply too big a job. For example, if pre-commercial thinning costs roughly $10 per acre, it would cost more than $1\frac{1}{2}$ million dollars to thin the 156,000 acres in poletimber and small sawtimber stands. Some of this area might be thinned without cash cost if saleable products could be produced. Still, the total cost would be large, many times any foreseeable budget for timber-stand improvement. Pertinent questions are: Where might stand improvement best begin? Where would benefits be large in relation to costs? Where would they be small? Also, how large a sum might profitably be spent on stand improvement?

The opportunities to be considered can be classified further in terms of forestry practices and stand conditions. It has already been shown that thinning is probably the most widely suitable practice, and that release and type conversion are other possibilities for some stands. Both the costs and response to thinning and other practices are affected by a wide variety of factors. Species composition (as reflected in forest types) and site productivity are two of these factors. (Accessibility might be another). These factors can be used as a simple basis of classification even though the bulk of the Elk State Forest is in one particular site-productivity class. The major stand conditions found on the Elk State Forest, together with area estimates for each, are listed in table 4.

Table 4. — *Area in poletimber and small sawtimber stands, by site class*

(In thousands of acres)

Forest type	Site classes			
	1	2	3	All sites
Hardwood types:				
Oak	([1])	72	8	80
Northern hardwood	1	65	1	67
Aspen	—	7	—	7
Mixed types:				
Oak-hard pine	—	1	—	1
Softwood types:				
White pine hemlock	—	1	—	1
Total	1	145	9	156

Source: Pa. Dept. Forests and Waters. FOREST MANAGEMENT PLAN FOR THE ELK STATE FOREST, 1955.

[1] Less than 500 acres.

A Simplified Analysis

There are many timber-management opportunities on the Elk State Forest. The major ones are in improvement of the pole-timber and small sawtimber stands that occupy nearly the entire forest. The area in these stands is divided somewhere near equally between the oak and northern hardwood types, with a small area in aspen poletimber stands, and negligible areas in oak-hard-pine and white pine-hemlock stands.

Of the oak and northern hardwood types, which stands offer the best opportunities for stand improvement and where would benefits be large in relation to costs?

This is a complex question if *benefits* and *costs* are interpreted broadly, because the Department of Forests and Waters has not one, but several objectives. The question can be simplified by first concentrating on one objective and introducing the others later. This simplified analysis will concentrate on the Department's primary timber-management objective: to obtain the greatest possible value response from funds invested in timber management.

Timber-management opportunities in Pennsylvania as a whole were analyzed recently (Webster 1960). In this analysis, each of three sets of forestry practices applied under a variety of stand conditions were ranked. The practices were: (1) planting open or lightly stocked forest land, (2) cleaning and cull-tree removal in hardwood seedling-and-sapling stands, and (3) thinning in hardwood poletimber stands.

These rankings were in terms of value response per cost dollar. A number of factors were considered. They included: (1) the physical costs of carrying out the selected forestry practices under a variety of stand conditions; (2) cost rates for converting physical costs to dollars; (3) physical response that could be expected under various conditions (including changes in gross volume, losses to fire, insects, diseases, changes in species composition and timber quality, and changes in the number of years required to produce mature timber); and (4) the prospective value of the mature timber.

These rankings brought together many different types of information—silvicultural, entomological, pathological, economic. A wide variety of sources—published, unpublished, and personal consultation—were drawn upon.

The thinning portion of this analysis deals with some of the timber-management opportunities available on the Elk State Forest. It can be used to compare opportunities for thinning. No comparable basis is yet available for comparing opportunities for pine release and for type conversion in oak stands. Comparisons in terms of thinning will give a minimum estimate of the value response obtainable from appropriate forestry practices under each of a variety of stand conditions. In a few cases, value response from release or type conversion might be greater.

Rating the Opportunities

The major timber-management opportunities on the Elk State Forest were ranked, using value response and cost data from the earlier analysis (table 5). This ranking provides information concerning the relationship between benefits and costs for four different management opportunities in oak and northern hard-

Table 5. — *Rating of timber-management opportunities on the Elk State Forest*[1]

Management Opportunity	Rate of return on additional investment	Value response per cost dollar		Increase in present net worth per acre[2]
		Discount rate 6%	Discount rate 3%	
	Percent	*Dollars*	*Dollars*	*Dollars*
Thin, northern hardwood, site 1	11.2	5	16	46
Thin, northern hardwood, site 2	10.3	4	13	32
Thin, oak, site 2	6.8	1.40	5	3.6
Thin, oak or northern hardwood on site 3 and aspen site 2	1.1	.20	.71	—7

[1] Rate of return, value response per cost dollar, and increase in present net worth were all calculated using data from Webster (1960).

[2] Future values discounted at 6 percent.

Table 6. — *Accomplishment at various levels of expenditures*

Expenditure level	Management opportunities	Increase in present[1] net worth of Elk State Forest
$5,000	Thin approximately 500 acres, northern hardwood, site 1	$23,000
$10,000	Thin approximately 1,000 acres, northern hardwood, site 1	$46,000
$25,000	Thin approximately 1,000 acres, northern hardwood, site 1, and approximately 1,500 acres, northern hardwood, site 2	$94,000
$50,000	Thin approximately 1,000 acres, northern hardwood, site 1, and approximately 4,000 acres, northern hardwood, site 2	$174,000
$100,000	Thin approximately 1,000 acres, northern hardwood, site 1, and approximately 9,000 acres, northern hardwood, site 2	$334,000
$500,000	Thin approximately 1,000 acres, northern hardwood, site 1, and approximately 49,000 acres, northern hardwood, site 2	$1,600,000
$1,000,000	Thin approximately 1,000 acres, northern hardwood, site 1, and approximately 65,000 acres, northern hardwood, site 2	$2,200,000
	Thin approximately 34,000 acres, oak, site 2	
$1,500,000	Thin all poletimber and small sawtimber stands (total 156,000 acres)	$2,200,000

[1] Future values discounted to present at 6% compound interest.

wood poletimber and small sawtimber stands. The relation of benefits and costs can be expressed in several different units: rate of return on additional investment, value response per cost dollar, and increase in present net worth. Rates of return range from a high of 11.2 percent for thinning northern hardwoods on site 1 to a low of only 1.1 percent for thinning oaks or northern

hardwoods on site 3 or aspen on site 2. The other profit measures give similar rankings.

These rankings constitute a priority schedule for timber management. If the data are correct, the greatest possible increase in timber values will be obtained by undertaking management opportunities in the order listed. For example, it is estimated that $10,000 dollars spent thinning northern hardwood stands on site 1 will increase the net value of the Elk State Forest by some $46,000 dollars (table 6), while the same amount spent for thinning oak stands on site 2 will increase the value by only $3,600.

Application

A schedule of priorities (table 5) can be used to guide management to the most productive opportunities. The managers of the Elk State Forest could use it to start management where benefits would be largest in relation to costs, and to proceed down the scale step by step.

However, additional information is required before such a schedule of priorities can be used. Many different kinds of stands are intermixed in the forest. Management planning could focus first on northern hardwoods on site 1. However, it would be extremely inefficient to actually thin all of these stands, and then go back and thin all the northern hardwood stands on site 2, and so on. Under many circumstances it would be more efficient to do all the work that is to be done in a given area before moving on to another area. What is the total job to be done at any given time? Or, how far down the schedule of priorities will any given budget reach?

The management opportunities that might be undertaken at a number of levels of expenditure (table 6) range from a very modest $5,000 to $1½ million dollars. For example, $5,000 could be used best to thin approximately 500 acres of northern hardwoods on site 1. Other opportunities would have to be ignored for lack of funds. With $50,000, it would be possible to thin all 1,000 acres of northern hardwoods on site 1 and also to thin 4,000 acres of northern hardwoods on site 2. Similar

Table 7. — *Cost schedule*

Management opportunity	Area	Average variable cost per acre	Total cost	Cumulative total cost
	Thousand acres	*Dollars per acre*	*Thousand dollars*	*Thousand dollars*
Thin, northern hardwood, site 1	1	10.50	10.5	10.5
Thin, northern hardwood, site 2	65	10.50	682.5	693.0
Thin, oak, site 2	72	9.00	648.0	1341.0
Thin, oak or northern hardwood on site 3, or aspen on site 2	16	9.00-10.50	160.0	1301.0

determinations could be made for any other level of expenditure, using the acreage and per-acre cost data in table 7.

But just what would be accomplished by taking advantage of the package of management opportunities that could be undertaken at any given budget level? How much would the additional timber be worth?

The increases in the present net worth of the Elk State Forest that would be produced by spending various sums in accordance with our schedule of priorities are listed in the last column of table 6. For example, expenditure of $10,000 to thin some 1,000 acres of northern hardwoods on site 1 would produce additional net values equal to $46,000 when discounted back to the present at 6 percent. Determinations for levels other than those listed can be made by using the value-increase data in the last column of table 5 and the acreage data in table 7.

How Big a Budget?

So far we have dealt with problems to be faced in the management of the Elk State Forest. In essence, we were concerned with how to spend a given budget. But there is a larger problem that must also be dealt with, at some higher level. That is the problem of how much money should be spent on timber

management on the Elk State Forest. How big should the budget be?

Economic theory provides one framework for answering this question. The greatest net benefit will be obtained from timber management on the Elk State Forest (or any other activity) if management is extended just to the point where an additional dollar spent will return an additional dollar in benefits. This point can be identified by using the rates of return for various management opportunities shown in table 5.

Suppose that other opportunities open to the Department of Forests and Waters are good enough that 6 percent is a minimum acceptable rate of return. In that case, all oak and northern hardwood poletimber and small sawtimber stands, except those on site 3, should be thinned. Thinning in all these stands promises returns greater than 6 percent. Therefore each dollar spent promises a return of more than a dollar. These stands occupy slightly less than 140,000 acres. If thinning costs about $10 per acre, a budget of $1.3 to 1.4 million would be justified (table 6).

Now suppose that other opportunities are somewhat better. Suppose that they are so good that 11 percent is the minimum acceptable return. Only thinning in northern hardwood stands on site 1 proimses a return greater than 11 percent. Therefore our analysis suggests that it is the only opportunity that should be undertaken. This would call for a much smaller budget. Some 1,000 acres would be involved, and a budget of approximately $10,000 would suffice (table 6).

Making the Decisions

Our analysis of major timber-management opportunities on the Elk State Forest is relatively simple. It ranks major opportunities, thereby supporting the proposition that timber management should start with those northern hardwood stands on highly productive sites and proceed, by stages as more money becomes available, down a scale ending with those oak stands on sites of low productivity. It measures the differences between opportunities in terms of benefit—cost relationships. Thus it

provides a basis for estimating the opportunity costs that would be incurred if opportunities were taken up in some other order.

The simplicity of the analysis stems from a number of assumptions made in carrying it out. There are three or four major assumptions. The first is that the sole objective of management is to produce additional timber at minimum cost; that is, to obtain the greatest possible value response from funds invested in timber management. There is a corollary to this assumption: that any complexity of management is acceptable so long as it increases value response per cost dollar. The second major assumption is that thinning in hardwood poletimber and small sawtimber is the only major timber-management opportunity. The third major assumption is that all data used in the analysis are perfect. The fourth major assumption (or perhaps a corollary to the third) is that all costs are readily measurable in terms of the inputs used in timber management.

How reasonable are these assumptions? Where do they depart from reality? And how might these departures affect timber-management decisions?

Allocating a Given Budget

The first three major assumptions affect allocation of a given budget. All depart from reality to one degree or another. The Department of Forests and Waters has not one but several objectives. Thinning in various kinds of hardwood stands is not the only timber-management opportunity available. And this analysis, like all others, uses information that is imperfect.

In addition to minimum-cost production of timber, the Department's objectives include efficient production of other forest products, keeping complexities of management to a tolerable level, and maintaining good relations with legislators, other agencies, and citizens. Furthermore, concentration of work in areas of limited employment opportunities is either another objective or perhaps a means of maintaining good relations.

The effects of other objectives are clearest in the case of wildlife production. During the fall and winter of 1961-62 the Pennsylvania Game Commission made thinnings and other

cuttings on some 5,800 acres for the primary purposes of providing additional deer browse in food-shortage areas. This acreage included some 800 acres on State Forest lands. The Department of Forests and Waters and the Game Commission selected stands for treatment on State Forest land. If these thinnings had been made to produce additional timber values at minimum cost, they would have been concentrated in northern hardwood stands on productive sites. It is here that benefits from timber production are largest in relation to costs (table 5).

However, the fact is that the stands thinned have been roughly half oak and half northern hardwood. Many food-shortage areas have been in locations where oak stands predominate. In these situations the Department of Forests and Waters and the Game Commission try to select for treatment oak stands on the more productive sites. Thus, the Department tries to pursue its primary timber-management objective but within restraints imposed by its wildlife-management objective. The objective of producing wildlife in an efficient manner has modified management on a relatively small area. If the Game Commission were able to expand its scale of operation, this objective might modify management on much larger areas.

Since the effects of other objectives are not so clear-cut, specific cases cannot be cited. It is apparent, though, that the effects are important. Given funds for management of immature stands, the Department of Forests and Waters would try to direct work toward areas of unemployment or limited employment opportunities. While this objective would primarily influence distribution of work among districts or other major sections of the State, it might also have some influence on distribution of work among sections of particular state forests like the Elk. There is obviously no reason for expecting the most profitable timber-management opportunities to coincide with areas of unemployment.

The objective of maintaining good relations has somewhat similar effects. Concentration of work in areas of unemployment may be one means of maintaining good relations. But, in any case, the interest of individuals and groups of citizens does have some effect on the location of work in Pennsylvania or in any

other state or jurisdiction. Almost any activity, including timber management, is more likely to be successful if it is undertaken in areas where people are interested in it. Thus the Department operates within an additional restraint in selecting the timber-management opportunities it will undertake. And this restraint probably influences distribution of work within Administrative Districts and State Forests, as well as between them.

Timber management may be influenced by the existence of other opportunities as well as other objectives. Thinning is not the only forestry practice that might be applied in predominantly oak and northern hardwood poletimber and small sawtimber. Release of understory pines and complete type conversion from hardwoods to softwoods are also possibilities in some of the poorer oak stands. These practices might bring about somewhat greater returns than thinning (table 5). This would decrease the differences in the returns promised by various opportunities. As a result, management of oak stands might appear somewhat more favorable than it does in our simplified analysis. Some parts of relatively small budgets might be devoted to management of these stands.

Finally, the information used in the analysis is imperfect. Both the response and cost data (Webster 1960) and the area estimates for the Elk State Forest are subject to error. Both types of data were obtained by sampling. In addition, the response and cost data were developed by combining information from a number of studies, and gaps were filled by using judgment estimates supplied by experienced foresters familiar with Pennsylvania conditions. As a result, both the profit measures used to rank timber-management opportunities and the auxiliary data used in other calculations might be represented better by either probability distributions or range estimates rather than by point estimates. Unfortunately the information necessary to calculate distributions or ranges is not readily available.

Nevertheless imperfections in the data can be recognized in a useful manner. When we inspect the rates of return promised by various timber-management opportunities, we see that they are 11.2, 10.3, 6.8, and 1.1 percent (table 5). Comparing

adjacent rates, which differences might be insignificant and which might remain even when data imperfections are taken into account? We cannot be sure, but we can probably make some informed guesses. The first two rates (11.2, 10.3) are particularly close, and the differences become progressively larger the rest of the way down the scale of priorities. We might be justified in concluding that the difference between the returns promised by the first two opportunities are insignificant, but that the other differences are significant, particularly the yawning gap between the last two opportunities on the list.

After reaching such a judgment, we could combine some of the opportunities. In this case, thinning northern hardwoods on sites 1 and 2 could be combined into a single opportunity, and the rest of the scale of priorities could be left as it is. Such combinations would simplify the manager's job in some respects, and would make it more complex in others. It would no longer be necessary, at low levels of expenditure, to find a small area of northern hardwoods on site 1, in the midst of a large area of northern hardwoods on site 2, and other kinds of stands. On the other hand, it would be less clear, in terms of planning, where a small budget might best be spent. In any event, however, the manager would be using data that represent reality more closely than would be the case if he assumed that all differences in return are significant no matter how small.

Thus a number of factors not included in the simplified analysis would influence budget allocation. Existence of other objectives and other opportunities might cause some shifting of priorities. Imperfect information would dull the analysis, giving a priority scale of only a relatively few opportunities.

Such an analysis will nevertheless be useful in allocating any given budget. Production of additional timber in an efficient manner is one of the objectives of the Department of Forests and Waters. Management for production of forest products other than timber is an important consideration on only relatively small areas of the Elk State Forest. And thinning in hardwood stands does encompass many of the major opportunities. Therefore this analysis can serve as a meaningful guidepost. It makes clear that

some timber-management opportunities are much better than others. And it provides a basis for separating the good opportunities from the poor ones that is more satisfactory than a one-aspect guide such as site-productivity. Imperfections in the available information mean that the guides are not so sharp as they might be. But some opportunities promise returns 10 times as great as those promised by others. Therefore a significant ordering of priorities has been accomplished.

Determining a Budget

Our analysis showed that modest budgets for timber management on the Elk State Forest would be justified even if a high return of more than 10 percent were the minimum acceptable. It further showed that truly large budgets would be justified if a moderate return of 6 percent were acceptable.

There is some evidence that the cost data used in this analysis are too low. It was assumed in the study on which this analysis was based that thinning would cost roughly $10 per acre. More recent information taken from operations of the Pennsylvania Game Commission suggests that roughly twice this figure—$20 to $25—might be more appropriate.[3] Higher costs would not change priorities because all of the management opportunities would be affected to the same degree. Their relative rankings would stay the same. But higher costs could influence budgets and the amount of timber management that could be accomplished. For example, suppose 6 percent were the minimum acceptable return and thinning cost $25 per acre. Under these circumstances, thinning in northern hardwood stands on sites 1 and 2 would still be justified (rates of return: 8.4 and 7.6 percent). But it would no longer be justified in oak stands on site 2 (rate of return: 4 percent). It so happens in this particular case that the budget would remain roughly the same.

[3] Thinnings carried out by the Game Commission have cost as much as $50 to $60 per acre. These costs were increased by factors that would not be present in thinnings carried out for timber rather than wildlife production: flattening of cut material, movement of brush, and performance of operations during periods of deep snow when deer food is particularly short. Straight timber-management operation might cost roughly half as much or less.

Higher costs per acre would offset a smaller number of acres, but obviously fewer acres could be treated and the resultant increase in the value of the Forest would be smaller. In other cases both the budget and the number of acres would decrease.

Even when higher costs are used, our budget calculations contrast sharply with the budget actually available. The managers of the Elk State Forest and other Pennsylvania State Forests now have no direct budget for management of immature stands. At present timber-management activities go little beyond sale of mature timber and related supervision. The only funds now available for management in immature stands are those available to the Pennsylvania Game Commission, and they are used primarily for wildlife-habitat improvement.

Why is there such an extreme contrast? One reason is that the overall budget for timber management in immature stands is beyond the control of the Department of Forests and Waters. When one is provided it will be done by the Governor and the Legislature. They will undoubtedly be influenced by the wishes and preferences of the citizens of Pennsylvania both as individuals and as organized groups. This is a higher level decision.

But why haven't the Governor and the Legislature provided any money when opportunities look quite favorable? Two explanations might be advanced. First, governors, legislators, and citizens may be unaware of timber-management opportunities. After all, they are busy people with many other things to think about. Second, they may consider opportunities that are not included in our analysis. If so, our assumption that all costs can be measured in terms of inputs involved in timber management is unrealistic.

And it is clear that the Governor, the legislators, and the citizens do consider other opportunities, many of them far removed from forestry. There is presumably some reasonable consensus on budgets for the state government as a whole at any given point in time. Within the limit implied, many extremely diverse activities compete with one another. Timber-management opportunities do not compete with each other at this level. Rather they compete as a group with expenditures for edu-

cation, highway construction, and mental health programs—to name only three examples. Furthermore, political considerations are obviously important, and legitimately so.

The diverse nature of the opportunities compared at this level means that our analysis of timber-management opportunities can contribute relatively little to the details of budget determination. A much broader analysis would be required. Even then the contribution of formal analysis may be relatively limited. Obviously it would be difficult, if not impossible, to reduce to a common scale the benefits of timber management, public education, highway construction, and mental health programs. Formal analysis may identify extreme cases of budgets too high or too low. This case may be one of these. However, other criteria (more subjective and political) will necessarily be used in determining the dollar amount of budgets. From the viewpoint of the managers of the Elk State Forest, then, budget determinations will be made by other people, using criteria quite different from those that they might use.

Perspective

This paper traces the usefulness and the limitations of a particular kind of economic analysis as a guide to timber management. At the outset it was described as a case study. Therefore no sweeping conclusions can be drawn. However, one striking tendency can be noted: the usefulness of the analysis for spending a given budget and its lack of usefulness for determining that budget.

The analysis was found to be distinctly useful in ranking timber-management opportunities. Admittedly it did not consider all of the objectives of the Pennsylvania Department of Forests and Waters nor all of the opportunities open to the Department. Nevertheless it did consider some of the major ones. For that reason the Department could see the rankings based on rates of return or other profit measures rather directly. Therefore a given budget available for timber management could

be spent more efficiently with the aid of this analysis than without it.

On the other hand, the analysis was found to be of little use in determining budgets. The difference between the large budget that could be justified and the budget actually available was striking. Some part of this difference may be attributed to lack of information. Governors, legislators, and citizens may be unaware of timber-management opportunities. But the difference is so great that all of it can hardly be attributed to lack of information.

An earlier analysis considered much the same point in a quite different context. It examined, on a conceptual level, the usefulness and limitations of economic analysis as a guide to three types of watershed-management decisions (Webster and Hagenstein).[4] It contrasted least-cost, fixed-expenditure, and production-goal decisions. In broad terms, least-cost and fixed-expenditure decisions involve questions of method. How can given changes in the quantity, quality, and timing of water flows be obtained most cheaply? How can a given budget be best spent to obtain the greatest possible benefit from changes in water flows? These decisions do not require measures of the value of water. Therefore conventional techniques of economic analysis can be used to provide guides to them. On the other hand, production-goal decisions involve questions of scale. How large a budget for watershed management will give the greatest net benefit? Measures of the value of water are required to determine net benefits. And, since water is rarely bought and sold by the unit at the watershed, economic analysis is not likely to be very useful in terms of guides to production-goal decisions.

An interesting insight is provided when this case study and the earlier analysis are brought together. In the earlier analysis it appeared that lack of prices established in commodity markets was what limited the usefulness of economic analysis in budget determinations. In the case study we have seen, however, that

[4] Webster, Henry H., and Perry R. Hagenstein. ECONOMIC ANALYSIS OF WATERSHED-MANAGEMENT DECISIONS: WHAT SORT OF GUIDES FOR LAND MANAGERS? Article submitted to Journal of Forestry, 1962.

something else is also involved. Timber is the product in the case study. It is sold by the unit in commodity markets and therefore prices are established. Even so, economic analysis is not particularly useful in determining budgets. Why?

Budgetary and political factors are often cited. This is right as far as it goes, but it doesn't go very far. Why is economic analysis so outweighed by budgetary and political factors in budget determinations?

The fact is that determination of budgets for timber management, watershed management, or almost any other activity often involves comparisons of some extremely diverse activities. For example, in the case of state programs of timber management in Pennsylvania, the relevant comparisons might be with education, highway construction, and mental health programs. It would be difficult to reduce the benefits of these activities to a common scale. Allocation of a given budget involves a much narrower range of alternatives. This case study provides an example. The alternatives were various timber-management opportunities in a limited geographic area. The benefits of these opportunities can be more readily reduced to a common scale. Therefore economic analysis could be quite useful in allocating a given budget, and at the same time quite ineffective in determining the size of that budget.

■

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CALIBRATING A WATERSHED

by using climatic data

Irvin C. Reigner

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CALIBRATING A WATERSHED by using climatic data

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A Problem of Calibration

TO DETERMINE some of the interrelationships that affect two of our most vital natural resources—forests and water—the Northeastern Forest Experiment Station of the U. S. Forest Service, the Pennsylvania Department of Forests and Waters, and the U. S. Geological Survey began in 1948 a cooperative research project on a tract of fairly typical scrub-oak land in the Pocono Mountain region of eastern Pennsylvania.

The general purpose of this project was to convert the brushy vegetation of the area to forests of commercial timber, and then to determine what effect this change in vegetation has on the water yields from the area.

A 2,089-acre tract of land was made available for the study. Containing the watershed of Dilldown Creek, a tributary to the Lehigh River, this area was dedicated as the Dilldown Unit of the Delaware-Lehigh Experimental Forest.

The first requisite was to calibrate the watershed: to determine the water-yield regimen of the area as it was with its original cover of brushy vegetation. This would serve as a datum basis against which the water regimen could be compared after the land had been converted to commercial forest, thus providing a measure of the change in water yield effected by the change in vegetation.

Meanwhile other studies were designed to test species, site preparation and planting methods, and other treatments for producing the commercial timber stands. These studies will not be discussed here.

The Dilldown Watershed

The Dilldown Watershed (fig. 1) is an area of 1,529 acres lying on the Pocono Plateau in northeastern Pennsylvania. Except for a riparian zone along Dilldown Creek, and several other small isolated spots, the watershed is covered with typical scrub-oak (*Quercus ilicifolia*) vegetation: scrub oak with associations of pitch pine, gray birch, sassafras, red maple, and red oak.

The soils of the watershed are stony to bouldery sandy loams with a leached A_2 horizon, and they range in depth from 2 to 5 feet. The mineral soil is covered with a tough fibrous mor humus that prevents erosion almost completely. There has been no evidence of overland flow.

The parent rock material is made up of two types of sandstone and one type of shale that is found only in a small area. The watershed has been glaciated by one or more of the earlier glaciers and apparently was in the periglacial zone of the Wisconsin glacier. Several boulder fields are present, which, along with numerous boulder streams, make up about 1 percent of the area. Swamps comprise about 5 percent of the area.

The sandstone and shale parent rock material provides a groundwater aquifer of moderate capacity. Analyses by Storey (1951) indicated a capacity of more than 5 inches under the total watershed area. If groundwater were at a high level to start with, groundwater flow would recede to about 0.7 c.f.s in 100 days if there were no groundwater recharge during the period. The lowest daily streamflow during the calibration period was 0.54 c.f.s.

Precipitation at the Dilldown Watershed is well distributed throughout the year. In a 10-year period of measurements, annual precipitation averaged 55 inches, which occurred in an average of 94 storms of 0.02 inch and larger. The highest 12-month precipitation was 76.84 inches; the lowest was 39.73 inches.

The watershed is completely forested, but only about 8 percent of the area is in high forest: riparian hardwoods and conifers along the creek and in swampy areas. The remaining 92 percent is in brush or what is generally called scrub oak. Actually a large part of the brushy area is covered by sprouts of tree species that would form a poor-quality high forest of mixed hardwoods and pitch pine if it were protected from fire for a long time.

A field survey in 1951 and 1952 showed that about half the total area was in the better hardwood and pitch pine types. Stands in which bear oak *(Quercus ilicifolia,* the true scrub oak

of this area) predominated covered only about 35 percent of the area, and only 3 percent was in pure scrub oak. Other brush types with little potential value, such as gray birch and aspen, covered the remainder of the area. Nearly all brushy types overtopped a dense ground cover of blueberry, sheep-laurel, and bracken fern.

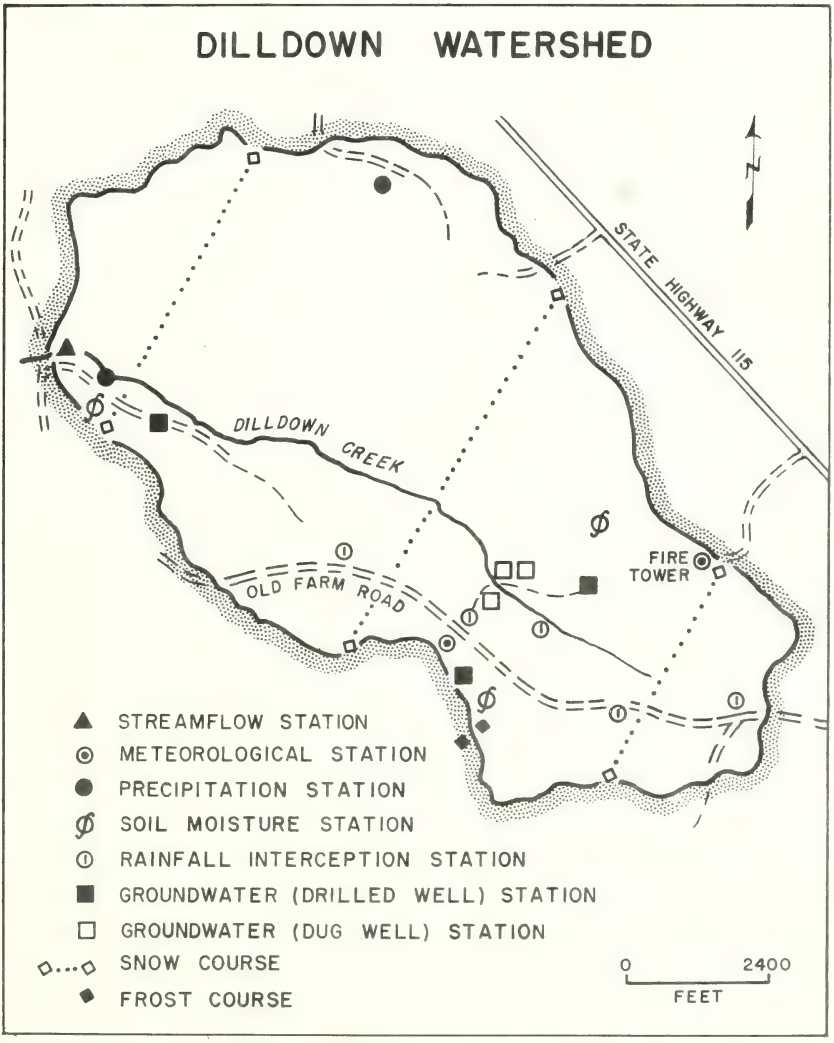

Figure 1. — The Dilldown Watershed, showing location of installations used to gather information used in the calibration.

Because the primary objective of the Dilldown Watershed study is to determine the effect on runoff of converting this brushy area to a high forest, the true scrub-oak areas have been planted to conifers wherever possible since the end of the calibration period. Areas too rocky to plant will be prepared for direct seeding by chemical treatment. Those hardwood and pine areas with sufficient density to form a closed canopy will be left untreated, while less dense stands will be reinforced with conifers. Every possible effort will be made to prevent wildfires from entering the watershed.

The Basic Approach

Choice of Method

There are two general methods of calibrating a watershed. One is to use a control watershed as a basis for comparison with a treated watershed. The other is to use a single watershed and calibrate it upon itself. This single-watershed calibration method was used in our studies.

In the control-watershed approach, streamflow of the untreated watershed is related to streamflow from the control watershed in a regression analysis. Once satisfactory correlation is achieved, the watershed is then treated and the regression can be used to detect significant changes.

To do this, improved analytic procedures, using statistical methods, have been developed by Wilm (1949), and elaborated on by Kovner and Evans (1954) and Reinhart (1956). These techniques have been used successfully to detect rather small changes in streamflow resulting from watershed treatment. They have been employed with good effect in almost all of the major watershed investigations.

The advantage of the control-watershed approach is its reliability: it is an established procedure with a background of experience and success. However, its disadvantages are several: a chance fire can completely change the character of the control; added costs are involved in installing and maintaining the control; it is difficult to locate two or more watersheds that are close together and physically similar; and the possibility exists that vegetation on the control can change after the calibration period.

The single-watershed approach is less costly because no control is involved, and the analysis is more informative because it relates streamflow to the factors that influence it rather than to

streamflow from another watershed only. Its principal disadvantage is its complexity: considerably more tabulation and analysis of data are required than with the control-watershed system.

Disadvantages common to both systems are the uncertainty, at the beginning of the calibration period, that correlations will be high enough to achieve usefulness, and the possibility that populations produced during the post-treatment period may be different from the populations produced during the calibration period.

In the single-watershed approach, the watershed is calibrated on itself: streamflow, usually the dependent variable, is related to those factors that influence it. Though this type of calibration has never been fully utilized, theoretically there might be four methods of accomplishing it. First would be a direct comparison of tabulated annual, seasonal, or monthly streamflow adjusted for differences in precipitation. Second, this rather crude approach could be amplified by plotting the accumulated value of precipitation and runoff, giving mass curves whose trend may indicate land-use effects. Mass curves, however, provide no measurement of random error. A third method is to detect changes due to treatment in the water balance procedure in which every bit of water is accounted for on a daily basis—so far an impractical method.

The fourth method, which we employed, is to use streamflow and climatic data obtained during the calibration period, and develop regression equations to predict monthly and annual runoff in terms of climatic factors. These equations will be applied during the post-treatment period and the estimated runoff will be compared with actual runoff. The differences, if any, will be tested statistically for significance and will be a measure of the effect of treatment. Schneider and Ayer (1961) have used this method to relate annual and seasonal runoff to precipitation and time-trend variables for several watersheds. They used relatively long-time records, which ranged from 19 to 25 years.

Streamflow and Climatic Records

The data used in this calibration analysis were obtained between October 1, 1948, and September 30, 1954, at the Dilldown Watershed. They include measurements of daily streamflow, precipitation, air temperature, and humidity. Groundwater and soil-moisture storage data were also used. These data have been published by the Pennsylvania Department of Forests and Waters in a series of three reports describing the Dilldown studies

Figure 2. — The weir and instrument shelter, where the streamflow regimen of Dilldown Creek was recorded.

(*Storey* 1951; *Storey, McQuilkin,* and *McNamara* 1953; *Reigner, McQuilkin, McNamara,* and *Lull* 1955). All data used in this analysis were included in the published reports.

Streamflow was measured at an automatic recording station (fig. 2) built and maintained by the U. S. Geological Survey. It consists of a Columbus deep-notch weir and Stevens A-35 water-storage recorder. All streamflow data were computed and tabulated by the Hydrographic Service of the U. S. Geological Survey and the Pennsylvania Department of Forests and Waters.

Precipitation data were the simple averages of the amounts caught in four recording gages spaced fairly uniformly around the margins of the watershed (fig. 3). All gages were equipped with Alter-type windshields. Temperature and humidity were measured at two standard Weather Bureau type climatic shelters, each of which included maximum and minimum thermometers and a recording hygrothermograph.

Groundwater storage at the beginning and end of each month was calculated according to methods outlined by Storey (1951). In the first method, the average level of two groundwater wells

was related to the groundwater yield of that level. The second method utilized the base-flow/groundwater-yield relationship. Results of the two methods checked closely. However, the first method was more accurate during summer periods, when riparian losses obscured base-flow observations; and the second method was more accurate during fall recharge periods, at which times one of the wells lagged behind actual recharge.

The soil-moisture storage values used in the analysis were the weighted averages of measurements at four stations located within the watershed. At each station, a stack of seven fiberglas Colman resistance units had been installed in a vertical series corresponding to the different soil horizons. These installations measured soil moisture to a depth of 27 inches, below which the soil was too rocky to insert the units. The measurements did not begin until October 18, 1949, about a year after the other measurements were started. They were continued, with some exceptions, five times per week throughout the calibration period. Some interpolations were required for the month-end values when they occurred on weekends.

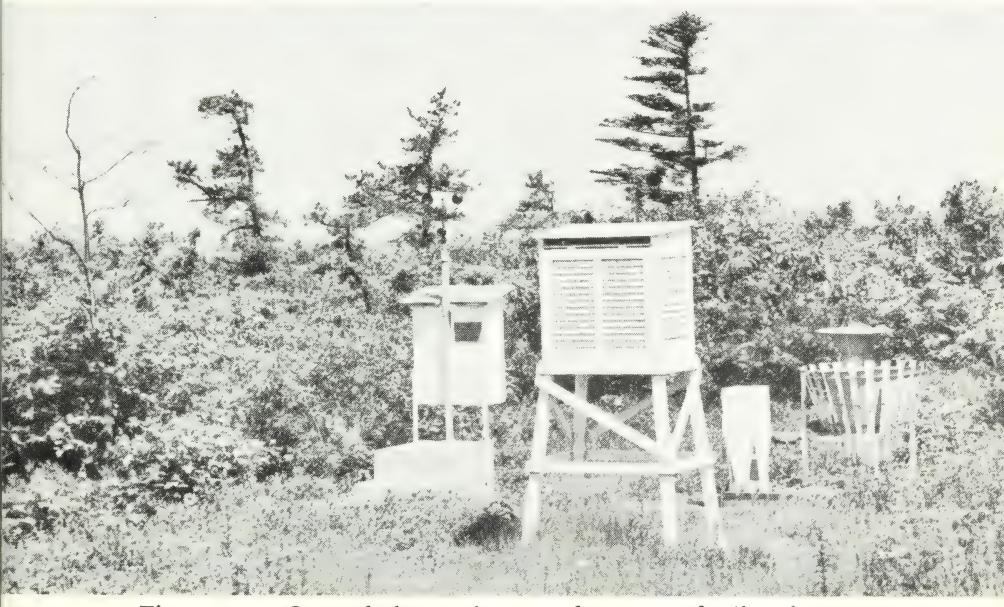

Figure 3. — One of the stations used to record climatic data on the Dilldown Watershed. The vegetation in the background is fairly typical of the scrub-oak cover on the area.

Limitations in Data

Storage values ranged considerably in accuracy. Groundwater storage estimates were fairly accurate. Soil-moisture values were weighted averages of the measurements at four index stations. Their accuracy on a watershed basis was only fair. Snow storage was measured periodically on snow-course lines at other permanent stations. On a watershed basis, snow-storage data were relatively inaccurate.

Measured storage values were not admissible because they would be subject to change by treatment. But they were useful in defining the relationships between runoff and streamflow. In a later analysis, they were in turn estimated from climatic data and the estimates were inserted in the equations.

For statistical purposes, annual and seasonal comparisons were limited by the 6 years of record which, by restricting degrees of freedom in multiple regression, sets up drastic limitations for statistical significance.

The use of monthly data, by providing a greater number of samples, overcomes the limitation of degrees of freedom. However, here the question of serial correlation is involved; i.e., the monthly values might be not independent but related through antecedent effects with each other. This objection was largely taken care of by using antecedent effects in the prediction equation.

The prediction of annual and monthly water yield was limited to those independent variables that would not be affected by treatment. This limitation set the pattern for the entire analysis, beginning with the basic equation:

Runoff = Precipitation — Evapotranspiration ± Storage Change

Obviously the evapotranspiration factor and storage change in groundwater levels, soil moisture, and snow could be affected by the treatment. Therefore it became necessary to predict these from climatic factors that would not be affected by treatment. This required the development of expressions of precipitation and air temperature for predicting evapotranspiration and storage change. These expressions could then be substituted in the basic equation, and runoff could be predicted. This procedure was used to develop prediction equations first for annual runoff and then for monthly runoff.

Annual Runoff

Annual runoff is often predicted from annual precipitation on the basis of the hydrologic year in which beginning and ending dates are selected that minimize storage change. To determine the most likely year, annual runoff-annual precipitation regressions were computed for hydrologic years beginning with each of the 12 months, and the standard error of estimates and correlation coefficients were calculated. Standard errors of estimate ranged from a December value of 0.20 inch to a September value of 3.77 inches (average annual runoff was 32.22 inches), with corresponding correlation coefficients of 0.9998 to 0.940. Apparently, there was no relation between degree of correlation and variation in groundwater and soil-moisture storage, nor any logical reason for the variability in correlation from month to month. The high correlations were judged to be happenstances and were not acceptable.

The Hydrologic Year

The U. S. Geological Survey uses a hydrologic year that begins October 1 and ends September 30, on the assumption that groundwater levels are lowest at that time of year and that storage variation is least at that time. Other watershed researchers have tested hydrologic years beginning on dates other than October 1. According to an unpublished report, an analysis was made at the Coweeta Hydrologic Laboratory in 1951 by the Southeastern Forest Experiment Station, using each of the months as the beginning of a year of record. Regression of runoff on precipitation showed the lowest standard deviation, 3.65 inches, for the May 1-April 30 year.

Brakensiek (1957) has propounded the use of an optimum water-year for agricultural watersheds, based on the uniformity of soil-moisture levels. The latter are at a maximum and are relatively uniform in the spring of the year. Thus the optimum water-year would begin with one of the spring months. As soil-moisture records were not available for most locations, however, a simple correlation between precipitation and runoff was used instead. Correlation coefficients between precipitation and runoff were computed for all 12 possible years. The year having the highest "r", the one chosen as the optimum water-year, coincided closely with maximum soil-moisture level.

The optimum water-year should coincide with those months having the least variation in groundwater and soil-moisture stor-

Table 1. — *Average groundwater and soil-moisture storage at beginning of each month, 1948-54, in inches*

At beginning of—	Groundwater storage		Soil-moisture storage		Groundwater plus soil-moisture storage: standard deviation
	Average	Standard deviation	Average	Standard deviation	
January	2.93	0.72	6.74	0.20	0.93
February	3.02	.90	6.92	.13	.89
March	2.80	.65	6.95	.23	.61
April	3.69	1.24	6.93	.18	1.35
May	3.30	.70	6.88	.30	.69
June	2.94	.81	6.97	.27	.89
July	1.51	.21	5.68	.52	.66
August	1.23	.47	5.54	1.13	1.31
September	.86	.45	5.61	1.19	1.32
October	.71	.48	6.28	.48	.67
November	.88	.35	7.02	.46	.85
December	2.34	1.00	6.99	.22	.87

Table 2. — *Precipitation-runoff regressions for hydrologic years beginning with different months*

Year beginning with—	Average annual precipitation	Average annual runoff	Regression coefficients		Standard error of estimate	Correlation coefficient
	X	Y	a	b	$s_{y.x}$	
January	57.74	34.73	—13.09	0.83	2.16	0.979
February	57.16	34.06	—13.45	.83	1.15	.995
March	57.35	33.86	—15.64	.86	3.14	.966
April	58.02	34.12	—18.23	.90	2.38	.977
May	57.86	34.02	—17.28	.89	2.61	.972
June	57.24	33.72	—14.59	.84	2.61	.975
July	57.44	33.68	—19.22	.92	1.19	.995
August	56.94	33.64	—16.74	.88	.92	.996
September	56.96	33.60	—13.29	.82	3.77	.940
October	56.82	33.58	—10.26	.77	2.82	.971
November	58.16	34.53	—12.18	.80	2.18	.977
December	57.75	34.52	—12.52	.81	.20	.9998
Average for all years		—	—14.71	.85	2.32	—
Average for years beginning during growing season		—	—15.23	.85	2.52	—

age. Table 1 shows the groundwater and soil-moisture storage pattern at the beginning of each month. Average values are lower during the summer and fall months because of high evapotranspiration rates. But the deviation of soil-moisture values is higher in the summer months than in other months, varying from field capacity after a long rainfall to near the wilting point after a long dry period. The standard deviations of groundwater-storage values show a less consistent pattern than those of soil-moisture values, although they are generally smaller in the summer months. The low standard deviation at the beginning of July is not a normal occurrence but is due to abnormally low rainfall in most of the June months during the calibration period. June rainfall averaged only 2.53 $\pm$ 1.16 inches in an area of well-distributed rainfall averaging 4.5 inches per month. In fact, long-term records at several Weather Bureau stations in the area show that June rainfall is somewhat above the average of all months.

Table 2 gives the correlation coefficients for hydrologic years beginning with each of the 12 months. A generally random pattern of the correlation coefficients and standard errors of estimate is evident. They are not even well related to the storage variation shown in table 1. The best correlation, by far, was obtained in the hydrologic year beginning December 1, at which time groundwater variation was great and snow storage was also a factor. Snow was measured on the watershed at the beginning and ending of each of the December 1 years, in greatly varying amounts. The August 1 years, which had the second best correlation, also had very large storage changes, as noted in table 1. These high correlations and the relatively poor correlation in the September 1 years are the result of other factors and will be explained in a later section. They are definitely not associated with time of year and therefore are not reproducible; that is, the high correlation observed in December 1 years probably will not be obtained in another group of December 1 years, such as the post-treatment period.

Water Losses by Hydrologic Years

Another method of relating precipitation (P) and runoff (RO) is to minimize the variation of annual water loss, which may be expressed as P — RO, or from the basic equation: Evapotranspiration $\pm$ Storage Changes. The hydrologic year with very low water-loss variation could also be used to predict streamflow. The results of such an analysis (table 3) show that the July 1

Table 3. — *Annual water-loss variation for hydrologic years beginning with different months*

(Water Loss = Precipitation — Runoff)

Year beginning with—	Average annual water loss	Standard deviation
January	23.01	2.63
February	23.10	2.23
March	23.49	3.17
April	23.89	2.33
May	23.91	2.62
June	23.54	2.92
July	23.75	1.31
August	23.30	1.49
September	23.34	3.82
October	23.44	3.40
November	23.63	2.85
December	23.23	1.89
Average for all years	—	2.56
Average for years beginning during growing season	—	2.59

year has the least variation. A similar analysis at the Coweeta Hydrologic Laboratory in 1953 showed the least variation in water loss within the April 1 year and the May 1 year.

The water-loss analysis has even less value than the precipitation-runoff relationship. The standard deviations of water loss are higher in all cases than the standard errors of estimate from the previous regressions. The lowest variation, in the July 1 years, is the result of uniform June rainfall, a happenstance, as discussed previously. The standard deviations in the water-loss analysis were higher than those in the precipitation-runoff analysis because the relationship of water loss to precipitation has not been taken into account. Water loss is affected by precipitation in that greater precipitation results in greater availability of water for evapotranspiration or other loss.

Using the average regression coefficients in table 2, an equation to predict runoff from precipitation might be expressed:

$$\text{Annual Runoff} = 0.85\ \text{Annual Precipitation} - 14.71$$

The b coefficient (0.85) demonstrates that not all increase in precipitation goes into streamflow: part of the increase is lost

in evapotranspiration or otherwise. For example, using the above equation:

40 inches of precipitation = 19.29 inches of runoff

and

70 inches of precipitation = 44.79 inches of runoff

In the first case, water loss would be 20.71 inches; but in the second case it would be 25.21 inches. In fact, if water loss were related to precipitation in a series of regressions, the standard deviations would be exactly the same as the standard errors of estimate shown in table 2.

Prediction of Annual Runoff from Precipitation, Measured Storage Change, and Estimated Evapotranspiration

To determine if storage changes were the only other factor besides precipitation that affects runoff, measured values of storage change were introduced as an independent variable in multiple regression equations.

First, annual runoff was related to precipitation and measured storage change (the sum of changes in groundwater storage, soil-moisture storage, and snow storage from one year to the next). Then the runoff was related to precipitation and evapotranspiration (estimated from mean annual temperatures and from potential evapotranspiration); and finally it was related to precipitation, measured storage change, and estimated evapotranspiration.

This final regression produced standard errors of estimates that ranged from 0.06 to 2.12 inches, and averaged 1.03 inches as against the 2.32-inch average for estimates based on precipitation-runoff only. These regressions were further improved (1) by dropping from the record those hydrologic-month years beginning in the winter months when snow had been an important but highly variable storage component, and (2) by utilizing groundwater storage data only in the storage-change estimates, dropping the less accurate soil-moisture data.

Relative to this point, storage changes were taken from the hydrograph or were actually measured. To meet the objectives of the calibration, storage changes estimated from antecedent climatic factors were required.

In relating annual runoff to precipitation and measured storage change, the regression equation took this form:

$$\text{Runoff} = a + b_1 \text{ Precipitation} + b_2 \text{ Measured Storage Change}$$

Table 4. — *Annual runoff regressions for hydrologic years beginning with different months*

Year beginning with—	Runoff on precipitation and measured storage gain			Runoff on precipitation and estimated evapotranspiration			Runoff on precipitation, measured storage gain, and estimated evapotranspiration			
	b_1	b_2	$s_{Y.12}$	b_1	b_3	$s_{Y.13}$	b_1	b_2	b_3	$s_{Y.123}$
January	0.81	—0.54	2.28	0.86	—0.84	2.40	0.85	—1.05	—1.85	1.39
February	.81	+ .72*	.36	.85	— .91	.69	.81	+ .66*	— .10	.50
March	.88	—2.31	2.50	.94	—2.86	.46	.94	+ .24*	—3.04	.60
April	.90	— .26	2.82	.96	—2.11	.82	.96	— .28	—2.12	.24
May	.90	—1.09	2.74	.91	—2.93	1.48	.92	— .93	—2.80	.63
June	.90	—1.06	2.20	.91	—1.48	2.89	.98	—1.13	—1.74	2.12
July	.96	+ .08*	1.21	1.02	—1.98	.63	1.03	+ .43*	—1.76	.70
August	.88	.00	1.10	.70	+2.19*	.86	.70	— .06	+2.21*	1.21
September	.81	—1.29	.71	1.16	—5.07	1.68	.82	—1.28	— .05	1.00
October	.82	—2.13	1.12	.93	—2.55	2.14	.85	—1.81	— .62	1.45
November	.77	—1.42	.37	.92	—1.94	.40	.84	— .76	— .93	.33
December	.81	— .08	.20	.81	+ .08*	.25	.82	— .20	— .26	.06
12-year average	0.85	—0.78	1.74	0.91	—1.70	1.49	0.87	—0.51	—1.09	1.03
Average for years beginning during growing season	.88	— .91	1.67	.94	—1.97	1.79	.87	— .80	— .79	1.29
Composite regression for growing season	.86	—1.03	1.51	.97	—2.29	1.59	.95	— .80	—1.69	1.16

b_1 = Regression coefficient for precipitation.
b_2 = Regression coefficient for measured storage gain.
b_3 = Regression coefficient for estimated evapotranspiration.

$s_{Y.12}$ = Standard error of estimate in multiple regression.
* = Coefficient has wrong sign; probably impossible.

Equations were calculated for all hydrologic years. The results are tabulated in the first section of table 4; and though the average error is lower than that shown in table 2, the individual errors are still relatively large. The two marked with asterisks show a positive relationship: they say, in effect, that runoff would be increased by a gain in storage. This was obviously incorrect, and the low standard error of estimate in February was a chance occurrence.

Even though the storage values were thought to be inexact, the errors of estimate were greater than might be expected. Apparently the other component of the basic equation—evapotranspiration—had enough variability to cause a part of these errors. Thus another variable had to be added to the multiple regression to remove this source of variation.

Evapotranspiration

In the search for a suitable variable that would be well related to evapotranspiration, the moisture-storage data available in this study were utilized. From the basic equation, a measurement of annual evapotranspiration was obtained:

Evapotranspiration = Precipitation — Runoff ± Storage Change

A simple and readily available value that might be expected to be related to annual evapotranspiration was mean annual temperature, the mean of daily average temperature computed from the maximum and minimum temperature. This value was well related to annual evapotranspiration under certain conditions in which other factors were constant. For example, in consecutive hydrologic years beginning in 1949, there was a decrease in evapotranspiration that was highly correlated to a decrease in annual temperature:

Year beginning 1949	*Measured evapotranspiration (inches)*	*Mean annual temperature, (°F.)*	*Sums of temperature over 30°F./100*
May	22.2	46.2	140
June	21.2	45.9	137
July	21.5	45.3	134
August	22.1	45.0	131
September	20.8	44.7	129
October	19.3	44.7	128

Another expression of annual temperature was also investigated: the summation of temperatures over a designated level. Budyko (1956) found a very close correlation between the sums

of temperature higher than 10° C. and radiation balance. Budyko (p. 170, Weather Bureau translation) explained his procedure as follows: "The sums of temperature higher than 10° is obtained by adding up mean daily temperatures in the Centigrade scale for the period when these temperatures are higher than 10°."

The procedure used in our analysis was slightly different but followed the same principle. The value 30 was subtracted from each daily maximum and minimum temperature in the Fahrenheit scale and the remainders were summed. No minus values were used, and all temperatures of 30° F. and below were therefore ignored. Perhaps a better system would entail the summation, or average, of 2-hour samples, as taken from a thermograph, instead of only two samples per day. But this would be a much longer process, and a thermograph might not be available in all watershed studies.

The summation of temperatures over a limit is a more logical approach than the use of daily means, because it is the higher temperatures that relate to evapotranspiration. Low temperatures —say 30° F. and lower—probably have very little relationship to evapotranspiration. But when averaged with higher temperatures, the means are considerably affected. It is hard to say what the correct level may be, whether 30° F. or 10° C. (50° F.) or some other temperature; but the summations over 30° F. gave good results in most cases. It should be noted that in monthly relationships the summation of temperatures over 30° F. would be perfectly related to mean monthly temperature in the summer months, when minimum temperatures do not fall to 30° F.

A serious weakness in the use of an expression of temperature to estimate evapotranspiration is that temperature is related to potential evapotranspiration and not necessarily to actual evapotranspiration. If an adequate supply of moisture were always available to satisfy the demands of potential evapotranspiration, the temperature variable would be well related to actual evapotranspiration. But moisture deficits occur frequently and should be recognized if possible.

Thornthwaite and Mather (1955) have devised a procedure for estimating monthly evapotranspiration: mean monthly temperature is used to estimate potential evapotranspiration; then this value is adjusted by the amounts of precipitation and stored moisture available for consumption.

As these procedures used climatic data rather than hydrograph data, they were useful in the calibration analysis. Monthly evapotranspiration was estimated according to Thornthwaite and

Mather's method, and the monthly figures were summed to give an estimated evapotranspiration value. The improvement over temperature in its correlation with measured evapotranspiration is shown in the following example:

Years beginning September	*Measured evapotranspiration (inches)*	*Sums of temperature over 30°F./100*	*Estimated evapotranspiration (inches)*	*Annual precipitation (inches)*
1949	20.8	129	20.0	46.0
1950	23.4	134	21.8	60.3
1951	26.9	136	22.5	72.5
1952	23.2	139	20.9	59.0
1953	22.9	142	21.5	47.0

It is also evident that the measured evapotranspiration, which may include other water losses besides evapotranspiration, was very well related to annual precipitation values. This suggests that annual precipitation, already a variable in the runoff equation, would take care of the moisture availability factor. But this is not always the case. Records are available for several years following the calibration period, in which annual precipitation was high but poorly distributed during the growing season. In these years, evapotranspiration was restricted by moisture deficits and lower than expected.

The estimated evapotranspiration values were not exact enough for adjusting the dependent variable in this analysis, but were considered an index of evapotranspiration; thus they were used as an independent variable in multiple regression.

The results of regressions in which estimated evapotranspiration was used are given in table 4. In the middle section it is used with precipitation only, while in the right-hand section it is used with the two other independent variables. While there is still considerable variation between the hydrologic years, the average errors of estimate show an improvement due to the inclusion of estimated evapotranspiration.

The causes of the peculiar correlations discussed earlier were evident at this point. An examination of the extremely high correlation between precipitation and runoff in the December 1 years revealed that there was a high negative covariance between the other two independent variables in the multiple regression. They cancelled each other; i.e., those years with a high storage gain had low evapotranspiration and vice versa. An almost perfect precipitation-runoff relationship remained.

On the other hand, the September years showed a particularly poor correlation between precipitation and runoff. In these years,

the two other independent variables were practically unrelated, and the variation in the storage change variable was extremely high — higher than in any other hydrologic year. Thus the deviations in the simple precipitation-runoff regression were related to the changes in storage and were minimized by the addition of this variable.

Deletion of Years Affected by Snow Storage

Some of the regressions listed in the right-hand section of table 4 were still obviously inaccurate; those for February, July, and August years had regression coefficients with sign opposite to what might be expected. Without much doubt, this was caused by inaccurate data in the storage-change variable. One known source of inaccuracy in the storage-change variable was the snow data. These were known to be relatively inexact on a watershed basis, thereby causing the storage-change variable to have large inaccuracies. For this reason, those years in which snow storage was a factor were deleted from the subsequent analysis. Remaining were those years beginning with the months May through October.

Inaccuracy of Soil-Moisture Storage Data

Even in these six hydrologic years, the storage-change data were obviously inaccurate, as shown in the third section of table 4. Almost certainly this inaccuracy was the result of the relatively inexact measurement of soil moisture on a watershed basis. Even though the soil moisture may have been measured accurately at the measuring stations, the great variation of soil depth, texture, rock content, and so on throughout the watershed made an exact estimate of watershed soil moisture an impossibility.

To test the relative accuracy of the two storage variables, regressions were computed for the six hydrologic years, May through October, using groundwater storage change instead of total storage change. The results (table 5) indicated an improved standard error of estimate in three of the six hydrologic years. More important, a greater consistency of the regression coefficients developed. The positive b_2 coefficient in the July years which say, in effect, that a gain in storage would result in increased runoff, became a reasonable negative coefficient. The high positive b_3 coefficient, which would indicate an increase in

Table 5. — *Annual runoff regressions for hydrologic years, beginning with different months*

Year beginning with—	Runoff on precipitation, estimated evapotranspiration, and total measured storage change	Runoff on precipitation, estimated evapotranspiration, and groundwater storage change			
	$s_{Y.123}$	b_1	b_3	b_4	$s_{Y.134}$
May	0.63	0.94	—3.35	—1.10	0.30
June	2.12	.97	—1.90	—1.38	1.14
July	.70	1.02	—2.14	— .88	.78
August	1.21	.87	+ .02*	—1.26	.54
September	1.00	1.15	—4.45	—1.43	1.68
October	1.45	.94	—2.15	— .86	2.87
Average	1.29	.98	—2.33	—1.15	1.49

b_1 = Regression coefficient for precipitation.
b_3 = Regression coefficient for estimated evapotranspiration.
b_4 = Regression coefficient for groundwater storage change.
$s_{Y.134}$ = Standard error of estimate in multiple regression.
* = Coefficient has wrong sign; probably impossible.

runoff with high evapotranspiration, became a small and nonsignificant coefficient when groundwater change was substituted for total storage change.

It would have been desirable to treat each storage change as a separate variable and to consider each value as an index of the true storage change. However, such a regression would have required four predictor variables. As there were only five samples in each hydrologic year group, four variables would allow no error measurement and, therefore, could not be used.

Combining Hydrologic Years

Dropping the hydrologic-month years influenced by snow storage left six hydrologic-month years, May through October. To develop prediction variables for storage, these years were combined into 30 years (6 hydrologic-month years x 5 years of record). Although the estimate of error from such a regression may not be valid, the relative value of each variable is assessed quite accurately because there are many more combinations of variables available for testing.

The procedure invited serial correlation. Though this limitation was recognized, the procedure was nevertheless adopted ini-

tially to gain information on independent variables. Further analysis suggested that much or all of the serial correlation was removed by the use of antecedent variables.

Economists commonly use time-series data that may or may not be serially correlated. They have devised tests to show evidence of serial correlation as well as procedures to adjust for it. In applying one of these tests (Durbin and Watson 1951), it was shown that residuals from the simple regression of runoff on precipitation were significantly serially correlated, as expected. The addition of the two independent variables—estimated evapotranspiration and total measured storage change—did not change the situation, although the residuals became smaller with the addition of each successive variable. In the tabulation of the individual residuals, the serial correlation, or lack of randomness in adjacent samples, was apparent. However, when groundwater storage gain and soil-moisture storage gain were treated as separate independent variables, the test was inconclusive at the 5-percent level of significance, but showed that the residuals were not significantly correlated at the 10-percent level.

Later analyses, using climatic variables in place of measured storage variables, showed a definite lack of serial correlation: the residuals were not seriously correlated at the 5-percent level. Thus the effect of the additional variables, two of which dealt with antecedent events, was to remove the influence of antecedent conditions.

Prediction of Storage Change

A simple variable related to annual storage change was the difference in precipitation between the last month of the runoff year and the same month of the preceding year. Using data taken from table 8, two examples of the relationship were devised:

	Precipitation (inches)	*Annual storage value (groundwater plus soil-moisture storage at end of month) (inches)*
(1) August 1953	1.37	4.32
August 1952	6.58	7.75
	−5.21	−3.43
(2) August 1954	6.04	7.46
August 1953	1.37	4.32
	+4.67	+3.14

The storage loss in the first example is related to the decrease in precipitation, while the storage gain in the second example is in accordance with the higher rainfall in the last month of the year.

Obviously watershed storage on any one day (say September 30) would be more intimately affected by rainfall on September 29 than by rainfall on September 1. Therefore a weighting system was required to give the later rainfall more weight than earlier rainfall.

Furthermore, storage on September 30 might also have been affected by rainfall in August or July admittedly to a lesser extent than rainfall during September. A longer antecedent period would be expected for the summer months when the groundwater-depletion curve is relatively flat (Storey 1951) and the effect of a storm that recharges groundwater will be long-lasting. On the other hand, during the winter and spring months, when the depletion curve is steep, the effect of a storm of similar size will last a much shorter time. Groundwater levels between the beginning of December and the beginning of June are generally much higher than in summer and fall months (table 1), and base flows are considerable greater. An accretion added to a high groundwater level will run off in a shorter time than if added to a low groundwater level.

A number of different antecedent periods were tested. In the system finally selected, the length of the period varied from month to month. The antecedent period for the year beginning with July was 80 days, for August 100 days, and for September and October 120 days. In years beginning with May and June, a 40-day antecedent period was used. Weighting, or transforming, was applied linearly; i.e., rainfall on the last day of the shorter period was given a weight of 40, the preceding day a weight of 39, and so on, decreasing 1 unit each day. The longer periods were weighted similarly: the last day's rainfall was given a weight equal to the total length of the period; then the weight was decreased 1 unit for each preceding day.

Antecedent Evapotranspiration

Storage was also affected by evapotranspiration during an antecedent period that created soil-moisture deficiencies. Groundwater recharge did not take place until these deficiencies were satisfied.

Records show that monthly potential evapotranspiration varies considerably from year to year. For example (table 6), potential

Table 6. — *Monthly adjusted potential evapotranspiration, in inches*

Year	April	May	June	July	August	September
1949	1.34	2.95	4.72	5.24	4.68	2.44
1950	.67	2.72	3.70	4.49	3.98	2.40
1951	1.30	2.95	3.98	4.88	4.25	2.91
1952	1.57	2.60	4.41	5.16	4.29	2.99
1953	1.18	3.31	4.45	5.00	4.41	2.91
1954	1.65	2.68	4.33	4.76	4.17	2.87

evapotranspiration for June 1950 was more than an inch less than that in June 1949. Thus the storage at the end of June 1950 might have been as much as 1 inch higher than at the end of June 1949, if rainfall had been adequate and similar for the 2 months.

A simple temperature variable, similar to the preceding precipitation variable, was also inserted in the regression. The mean monthly temperature for the last month of the antecedent year was subtracted from the mean monthly temperature for the last month of the runoff year. The difference obtained was also related to the storage change from the beginning to the end of the runoff year. A positive difference would result in a lower storage gain (or a storage loss), which would increase runoff for the year.

The temperature variable was expressed in a number of ways. For the years beginning on May 1, mean April temperatures were used; for years beginning June 1, the averages of April and May temperatures were used. Average monthly temperatures for the preceding 3 months were used in all other years; i.e., July through October years.

Correction for Direct Runoff

Direct or storm runoff, (the sum of overland flow, channel interception, and storm seepage) was produced in disproportionate amounts by large storms. The small storms produced little or no direct runoff, but almost 3 inches of the large 10-inch storm of July 1952 ran off quickly and had no effect on storage. Therefore a correction had to be made to reduce the effect of large storms on the storage relationship. As high monthly precipitation values are usually the reflection of large storms, the square root of monthly precipitation had the effect of adjusting for large storms.

Though the square root of monthly precipitation is a useful and rather simple expression of the precipitation entering storage, a more accurate but more complex method of correcting for large storms was devised. This method is presented in a later section that deals with the estimation of various storage factors. Estimated storage precipitation, as it is called in this paper, is an estimate of monthly precipitation minus monthly direct runoff. In all cases, the differences between these monthly values, from year to year, are the values used as one of the two storage-change variables.

Regressions Based on Combined Years

A series of multiple regressions were run with combined data, the best predictions employing annual precipitation (X_1), annual estimated evaporation (X_2), and the differences between weighted storage precipitation values and sums of temperature over 30° F. ($X_6 - X_7$). The equation took this form:

$$\text{Annual Runoff} = a + b_1X_1 + b_2X_2 + b_3(X_6 - X_7) + E$$

These three variables were then used with uncombined data, and a multiple regression was calculated for each of the six hydrologic years as follows:

Year beginning —	a	b_1	b_2	b_3	$S_{Y.123}$
May	55.60	0.96	—3.41	—1.90	0.45
June	40.71	.98	—2.71	—3.03	.72
July	26.50	1.02	—2.29	—1.13	.79
August	35.52	.77	+1.24	—0.93	.85
September	40.23	1.02	—2.84	—2.50	1.55
October	14.48	.90	—1.25	—3.48	2.21
Average	35.51	0.94	—1.88	—2.16	1.25

The following equations were calculated from regressions in which the six hydrologic years were combined to provide a population of 30 samples.

[1] $$Y = 18.99 + 0.95\,X_1 - 1.69\,X_2 - 0.80\,X_3$$

in which:

Y = annual runoff, in inches.
X_1 = annual precipitation, in inches.
X_2 = annual estimated evapotranspiration, in inches.
X_3 = total measured storage gain (sum of groundwater plus soil-moisture storage changes plus 4.00), in inches.

[2] $Y = 24.22 + 0.98 X_1 - 2.05 X_2 - 1.36 X_{3A} - 0.38 X_{3B}$

in which:

X_{3A} = measured groundwater gain (change in groundwater storage + 2.00), in inches.

X_{3B} = measured soil-moisture gain (change in soil-moisture storage + 3.00), in inches.

[3] $Y = 27.86 + 0.97 X_1 - 2.24 X_2 - 1.16 X_4 + 10.55 X_5$

in which:

X_4 = precipitation in last month of runoff year, in inches, plus 2.00 minus precipitation in last month of preceding year.

X_5 = sum of temperatures over 30°F./1000 for last month of runoff year + 0.40 minus sum of temperatures over 30° F./1000 for last month of preceding year.

[4] $Y = 31.08 + 0.98 X_1 - 2.36 X_2 - 2.37 X_6 + 10.94 X_7$

in which:

X_6 = differences between weighted storage precipitation for the end of each year + 2.00.

X_7 = differences between the sums of temperature over 30° F. for the end of each year + 0.40.

[5] $Y = 30.28 + 0.98 X_1 - 2.28 X_2 - 2.47 (X_6 - X_7)$

The mean squared residuals (the square of the standard error of estimate) of the preceding equations are as follows: (1) 1.35 inches, (2) 1.07 inches, (3) 0.98 inch, (4) 0.87 inch, and (5) 0.90 inch.

In equation 5, the two variables related to storage change have been combined into one variable, which may be considered the storage-change variable.

Equation 2, in which the two measured storage values were inserted separately, confirms the statement made earlier: soil-moisture storage values were rather inaccurate on a watershed basis. When combined with the more accurate groundwater data, the accuracy of the estimates decreases. Furthermore, the X_1 and X_2 coefficients in equation 2 are similar to those in equations 3, 4, and 5, whereas they are rather dissimilar in equation 1.

The reliability of the estimating equations was questionable because only 1 degree of freedom remained in each small population to measure error. Nor were the coefficients very accurate, as indicated by this lack of uniformity between the various equations. No reason can be given for the lack of uniformity, nor for this curious increase in the standard errors of estimate as

the seasons progressed. However, it is suspected that the low standard errors were the result of chance happenings of over-manipulation of the data.

However, all standard errors of estimate were well below the minimum practical change in yield we considered significant; namely, about 10 percent of the annual runoff, or about 3.2 inches.

One way to provide additional samples for multiple regression is to pool data from the calibration period and the post-calibration period. A dummy variable included in the regression would show the difference, if any, between periods. Such an analysis is similar to covariance analysis, but is probably more efficient than the latter in instances where the number of samples is limited, as in this case.

An analysis including a dummy variable was used with some success with a 4-year period of record following the calibration years. However, this was an unusual period in which occurred drought, hurricane rainfalls, and a wildfire that burned over about one-third of the watershed.

Another way to increase the reliability of the predicting equations is to provide more accurate estimates of evapotranspiration and storage changes. Research is continuing on methods to estimate evapotranspiration more accurately, and a large group of samples of storage changes would provide opportunity to estimate them more accurately.

Table 7. — *Basic data for annual runoff analysis*

Hydrologic year beginning with	Annual precipitation	Annual runoff	Estimated evapotranspiration	Groundwater storage change	Total storage change	Precipitation: last month minus antecedent month	X_3	X_4	X_3-X_4+1.60
May 1									
1949	48.97	26.86	21.47	—0.60	0.14	—2.67	—0.49	—0.26	1.37
1950	59.22	38.54	20.59	.44	— .26	1.29	.43	.22	1.81
1951	62.57	35.54	22.08	1.46	1.88	6.42	.97	.12	2.45
1952	72.36	46.95	22.24	— .80	— .79	—4.08	— .54	— .19	1.25
1953	46.11	22.30	22.25	— .92	— .65	—1.80	— .48	.28	.84
June 1									
1949	46.10	24.59	21.24	— .18	.28	—2.88	— .32	— .22	1.50
1950	58.04	37.73	20.82	—1.47	—1.67	—1.18	— .23	.21	1.16
1951	65.73	38.17	21.73	2.30	2.50	3.16	.86	— .25	2.71
1952	71.39	46.08	22.95	— .90	— .44	— .96	— .43	.33	.84
1953	44.96	21.96	21.62	— .80	—1.48	—1.15	— .59	— .30	1.31
July 1									
1949	48.26	25.47	21.12	.38	1.34	2.16	.14	— .26	2.00
1950	59.24	36.99	21.14	— .18	.32	1.20	.15	.18	1.57
1951	63.99	39.25	21.92	.10	—1.04	—1.74	.03	— .01	1.64
1952	70.75	45.37	22.80	— .22	— .34	— .63	— .27	.04	1.29
1953	44.91	21.34	21.54	— .28	— .01	— .06	— .16	— .02	1.46

CONTINUED

Table 7.—*Continued*

Hydrologic year beginning with	Annual precipitation	Annual runoff	Estimated evapotranspiration	Groundwater storage change	Total storage change	Precipitation: last month minus antecedent month	X_3	X_4	X_3-X_4+1.60
August 1									
1949	49.76	26.66	20.92	0.56	0.97	1.49	0.31	—0.29	2.20
1950	60.03	36.51	21.53	.16	1.24	.81	.39	.15	1.84
1951	68.41	42.89	22.20	.31	—1.44	4.40	.04	.00	1.64
1952	64.22	41.20	22.40	— .99	— .57	—6.51	— .64	.09	.87
1953	42.37	21.02	20.13	— .17	—1.95	—2.54	— .57	— .15	1.18
September 1									
1949	45.98	26.73	19.97	.08	—1.50	—3.75	— .47	— .29	1.42
1950	60.28	36.63	21.81	.08	.33	.25	.25	.09	1.76
1951	72.49	44.47	22.47	.68	1.13	4.06	.51	.09	2.02
1952	59.01	39.21	20.87	—1.16	—3.43	—5.21	—1.04	.00	.56
1953	47.04	21.04	21.54	— .12	3.14	4.67	.51	— .09	2.20
October 1									
1949	45.12	26.75	19.93	— .39	— .98	— .87	— .50	— .20	1.30
1950	59.96	36.62	22.32	.01	— .34	— .30	.11	.14	1.57
1951	75.86	47.22	22.55	.96	.91	3.36	.63	.10	2.13
1952	58.06	36.50	20.79	—1.30	—1.49	— .96	— .65	— .02	.97
1953	45.05	20.81	21.50	— .18	1.01	—1.98	.14	— .10	1.84

X_3 = Weighted storage precipitation: last period minus antecedent period.
X_4 = Sum of temperatures over 30°F.: last period minus antecedent period.

Monthly Runoff

The greater number of samples available for monthly prediction provided more opportunities for exploring pertinent relationships. Most of these involved the immediate disposition of rainfall into soil-moisture storage, groundwater recharge, or streamflow. Earlier analyses showed that snowfalls and snow accumulation upset the rainfall-derived relationships. Accordingly, all months were eliminated in which a snow cover had been recorded at the beginning or end. This left 49 months for analysis.

Monthly Water Loss as the Dependent Variable

The monthly water-loss value (precipitation minus runoff) was adapted as the dependent variable for a number of reasons:

1. Except in the December-April season, precipitation is much more closely related to water loss than it is to runoff. During the summer months, when there is low beginning storage, practically none of the precipitation becomes runoff. Even in the December-April season, precipitation is almost as well related to water loss as it is to runoff.

2. The weighting systems that are applied to daily precipitation were developed for storage estimation, as described in previous sections. They are weighted heavily at the end of the period and are applicable to the precipitation expressions for water-loss estimation. The weighting systems for runoff estimation, on the other hand, would be weighted heavily at the beginning of the period.

3. Storage precipitation, the expression that has been corrected for direct runoff, is equally useful for water-loss estimation because water loss is essentiallly a storage factor. The first general equation:

Runoff = Precipitation — Evapotranspiration — Storage gain

now becomes:

Precipitation — Runoff = Water loss = Evapotranspiration + Storage gain

Storage precipitation would not relate well with runoff, for it is total precipitation minus direct runoff. Direct runoff, of course, is a part of total runoff. If runoff were used as the dependent variable, direct runoff would have to be a separate independent variable.

The water-loss concept is confusing to some workers in this field who have considered consumptive use, evapotranspiration, and water loss as synonymous terms. Water loss, as used here, is more than just evapotranspiration; it is all rainfall during the period that does not show up at the streamgaging station during the period. Thus, storage gain during the month is a water loss for that month. Evapotranspiration is almost entirely a loss from soil-moisture storage (interception loss is a loss of potential soil-moisture storage), and therefore the two terms are complementary. If evapotranspiration is high in a particular month, storage gain will be low in comparison with another month having the same precipitation but low evapotranspiration. Ignoring evapotranspiration, the estimation of water loss is an estimation of storage gain; and therefore the expressions developed for estimating storage applied to the water-loss estimates as well.

Therefore an estimate of evapotranspiration was not required in this analysis. Except for a small amount of riparian water loss, evapotranspiration was not considered. Disregarding riparian water loss temporarily, monthly water loss could be related to just two factors: storage at the beginning of the month and rainfall during the month:

$$\text{Monthly Water Loss} = a + b_1 \text{ Precipitation} + b_2 \text{ Beginning Storage}$$

In the development of basic relationships, groundwater values and precipitation corrections were derived from hydrograph analysis. The beginning storage variable, for instance, was specifically the groundwater storage variable. Initial soil-moisture storage has no direct effect on water loss or runoff; it affects only groundwater recharge.

Expression of monthly precipitation required these steps: first, the straight monthly precipitation was determined; then calculations were made for the transformed values in which late-in-the-month precipitation was given greater weight than earlier rainfall because the one affected storage gain more than the other. Several weighting systems were tested and a system was developed based on linear weighting.

Weighting Precipitation

Several weighting systems were tested: logarithmic, reciprocal, and linear, as well as numerous levels within each system. In the linear system finally adopted, weights were varied according to groundwater level. In months with high beginning groundwater level, precipitation was weighted heavily; i.e., the last day's rain-

fall was given a weight of 40, decreasing one unit each day until the first day of the month, which had a weight of 10 or 11. Months with lower groundwater levels were weighted less heavily, on an 80-basis: the last day's rainfall was given a weight of 80 and the first day's a weight of 50 or 51.

Next, months were grouped to obtain uniform weightings based on groundwater levels. Four groups were formed: the two groups of lower groundwater were the summer and fall months, and the two high groundwater groups were the cooler months. In group I were months in which the total amount of water in underground storage could provide a runoff yield of less than 1 inch. Group II included all the other summer and fall months in which beginning groundwater was 1 inch or higher. Group III contained all May and June samples, while December through April months comprised group IV. In both groups III and IV groundwater at the beginning of all months was at relatively high levels—higher than any months in group II.

In group I, monthly precipitation was weighted very lightly, the first day of the month receiving only 4 percent less weight than the last day. Group II required a weighting on an 80-basis; and both cool-season groups were given a 40-basis weighting.

Finally, the relationship of precipitation to water loss was corrected for the amount of direct runoff from large storms. As direct runoff, or storm runoff, leaves the watershed immediately after the storm, it has no effect on groundwater or soil-moisture recharge. Measured on the hydrograph, daily direct runoff was subtracted from daily precipitation to give the storage precipitation value that was used in the prediction of annual runoff. This correction method was found to be much more accurate than the use of an exponential form of monthly weighted precipitation.

Relatively minor differences between months within groups were apparently the effect of riparian water loss. They were accounted for by an average length-of-day variable.

Estimates for May and June were improved by the addition of: (1) an interaction between precipitation and the average length of day, and (2) the sums of temperatures over 30° F.

Groundwater storage and weighted storage precipitation proved to be well related to water loss. But they could not be used to predict water loss after watershed treatment, for both were subject to change due to treatment. Substitutes for these values had to be derived that would not be affected by treatment.

Prediction of Groundwater Storage

Groundwater storage at the end of a month (GWS-E) was first estimated from antecedent groundwater and soil-moisture storage, measured at the end of the previous month, and storage precipitation (precipitation minus direct runoff) for the month. All three independent variables proved to be positive and significant.

The next step was to develop precipitation and temperature variables related to antecedent storage. The variables were aimed at expressing total storage, the sum of both groundwater and soil-moisture storages. Accordingly, daily weighted rainfall for varying periods was related to total storage, using the system described earlier. These values became the antecedent precipitation variable. Its period ended 1 month prior to the time of groundwater measurement.

Monthly analyses indicated that precipitation for the month in which groundwater was measured should not be weighted. Apparently, during the summer much of the rainfall in the month immediately preceding the time of measurement had little effect on groundwater storage; it was held by the soil, satisfying soil-moisture deficiencies, and therefore was not available for groundwater recharge. An estimate of soil-moisture storage would require a 30-day precipitation variable with increasing weight toward the end of the period. Thus an unweighted precipitation variable would be more closely related to groundwater storage.

Data for all the summer months—groundwater storage at the end of the months of June through August (GWS-E)—were combined in one regression of this form:

$$\text{GWS-E} = a + b_1P + b_2P_a + b_3T_a$$

in which:

P =Storage precipitation (unweighted) for the month of measurement.

P_a=Daily weighted storage precipitation for a variable antecedent period ending a month prior to groundwater measurement. The periods were 40, 80, and 100 days, respectively, for June, July, and August.

T_a=Sums of temperatures over 30° F. for the antecedent period.

As P_a is in part a measure of antecedent soil moisture, an interaction between P and P_a was indicated, the effect of P should increase as P_a increases. A product variable (interaction), *viz*

PP_a, was tested and was found to be consistent and highly significant in various monthly groupings, and was included as an additional variable.

An equation was next derived for months ending in September through November. It was similar to the one for the summer months, except that a 120-day antecedent period was used for all months.

The T_a variables (temperature) varied between monthly groups. For the June, July, and August groups, the sums of temperatures over 30° F. for the second and third months preceding the month in question were averaged. For example, in the estimation of GWS-E for June, sums of temperatures over 30° F. for April and May were averaged.

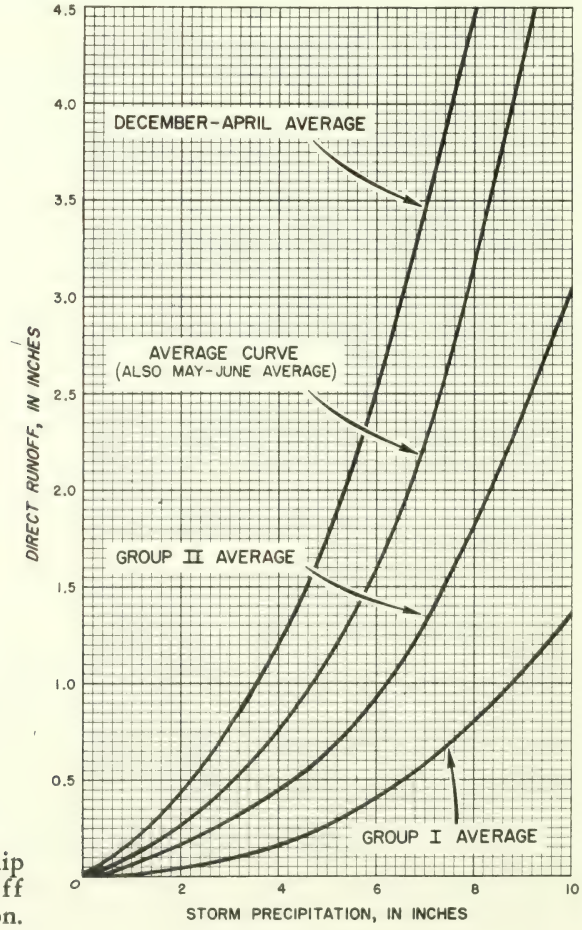

Figure 4. — Relationship between direct runoff and storm precipitation.

For the September, October, and November groups, sums of temperatures for the first and second months preceding the time of estimate were averaged; that is, for an estimate of groundwater storage at the end of October, the average sums of temperatures over 30° F. for September and October were used. The antecedent periods were determined by regression analysis, and the reason for the two different periods is rather obscure. It may be that during the summer months soil-moisture depletions were so great that the temperature during the measurement month had no effect on storage; whereas during the cooler fall months, soil moisture had begun to recharge and its level was affected by recent temperature events.

Fairly accurate estimates for April and May were obtained with an equation using daily weighted storage precipitation for a 40-day period and average monthly sum of temperatures over 30° F. since April 1. For April, only the sums of April temperatures over 30° F. were used. For May, averages of April and May sums were used.

Groundwater storage for the other 4 months of the year was estimated fairly well by use of a simple relationship with daily weighted storage precipitation. Temperature had no effect in these colder months; apparently there was little or no evapotranspiration or there was no difference between months.

Storage precipitation was originally calculated by means of hydrographic analysis. As the precipitation-direct runoff relationship may be affected by watershed treatment, an estimate of storage precipitation was substituted in the above equations.

Estimation of Storage Precipitation

Storage precipitation, that portion of total precipitation that remains on the watershed to evaporate or to go into storage, was mentioned briefly in the section on annual runoff and was discussed in some detail in the previous section on groundwater storage estimation. This section will deal with estimating storage precipitation from climatic factors.

The first attempt to approximate storage precipitation was by use of the square root of monthly precipitation in place of the linear expression of precipitation. The amount of direct runoff is closely related to size of storm, and large storms generally result in high values of monthly precipitation. Thus the square root of monthly precipitation almost always estimated storage better than the linear expression. But, although the square root

of monthly precipitation is easy to calculate, its relationship to storage precipitation is fairly rough. The following methods described, while rather complex, are highly accurate.

Relationship between Precipitation and Direct Runoff

First, direct runoff was plotted over total storm precipitation for a large number of storms during the calibration period. The scatter of points appeared to be well related to differences in antecedent conditions; so an estimate of total storage at the

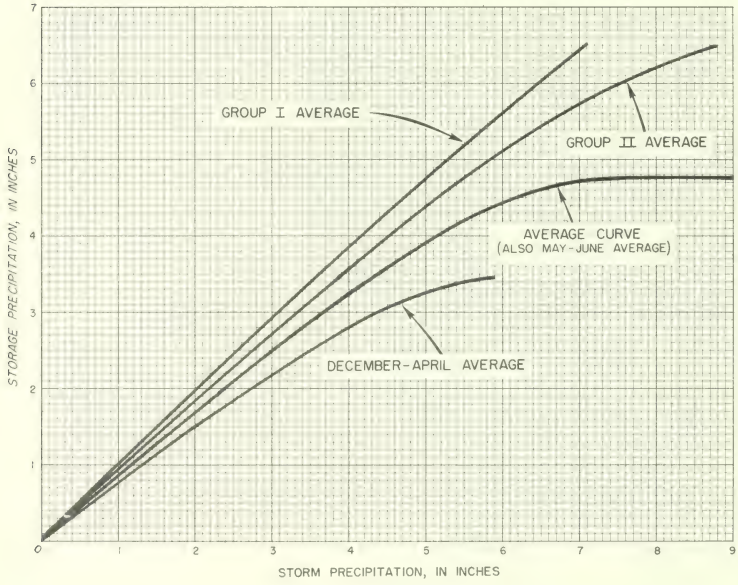

Figure 5. — Relationship between storage precipitation and storm precipitation.

beginning of the storm was assigned to each point and a curve was drawn through points representing average storage (fig. 4). The average curve was J-shaped, with a limitation in the higher values.

The curve of direct runoff over storm precipitation was converted to a curve of storage precipitation over storm precipitation. Direct runoff from the average curve on figure 4 was subtracted from its respective storm precipitation value. The remainder, stor-

age precipitation, was plotted over storm precipitation and the average curve was drawn on figure 5. This curve begins at a slope of 1.0, indicating no direct runoff up to this point; then the curve gradually becomes parallel to the abscissa, indicating that all precipitation over a certain amount becomes direct runoff.

Converting Storm Precipitation to Average Storage Precipitation

A table was prepared to convert storm precipitation to average storage precipitation, and the table was applied to the daily precipitation values for the entire period of calibration. Although storm precipitation was used to prepare the curves and table, it was applied to daily values without much loss of accuracy. There seems to be no way to tabulate precipitation on a storm basis, instead of a daily basis, and then to apply a uniform system of weights. Perhaps such a method could be devised, but it would complicate the procedures still further.

Tables of average storage precipitation were prepared by using daily precipitation in place of storm precipitation; monthly totals and weighted sums were also calculated. Naturally these average values would not be accurate for all months. The average curve would tend to overadjust in the summer months and underadjust in the winter months. At this stage in the analysis, the following tables of precipitation expressions were available:

a. Daily unadjusted precipitation.
b. Daily storage precipitation (unadjusted daily precipitations minus measured direct runoff).
c. Average daily storage precipitation (taken from fig. 5).

Correcting Average Storage Precipitation by Groups of Months

Obviously, expression (b) is a more accurate expression of storage precipitation than (c), and methods had to be devised to interpolate between and extrapolate from (a) and (c) to approximate (b). The 49 months used in the monthly analysis had been divided into four groups:

1. Twelve summer and fall months with low beginning groundwater storage.
2. Thirteen summer and fall months with high beginning groundwater storage.
3. Twelve May and June months.
4. Twelve winter months, December through April.

For each group, the totals of each expression were computed and a correction factor was determined by the following equation:

$$\text{c.f.} = \frac{\text{(a)} - \text{(b)}}{\text{(a)} - \text{(c)}}$$

Precipitation expressions

Group	*Unadjusted* *a*	*Storage* *b*	*From curve* *c*	*c.f.*
I	15.13	14.63	13.39	0.3
II	18.56	16.44	15.99	.8
III	14.94	13.38	13.53	1.1
IV	22.26	18.29	19.89	1.7

The previous equation was solved as follows:

$$\text{(b)} = \text{c.f.} \times \text{(c)} + (1 - \text{c.f.}) \times \text{(a)}$$

in which (b) was then an estimated value. One of the correction factors was applied to each month in its respective group and an estimate of monthly storage precipitation was calculated.

These estimated values were tested in the monthly runoff analysis. Though they gave better results than unadjusted values of precipitation, and better results than the square roots of precipitation, they still were not as good as the measured values of storage precipitation. Apparently the use of the group correction factor was still not precise enough. And the range of storage values within groups suggested that the correction factor should be varied month by month, depending on some storage variable.

Monthly Correction Factors

Going back to the three different expressions of precipitation, we computed correction factors for each month, as we did previously for the four groups. These monthly correction factors were then used as a dependent variable, to be estimated by some storage or climatic variable. A substantial portion of the variation had already been removed by the delineation into the four groups. As noted, the variation between groups was consistent and followed a pattern related to groundwater level.

Within groups, regressions were computed by using the following data as predictor variables:

Groundwater storage at the beginning of the month.
Groundwater storage at the end of the month.
Average groundwater storage.

Precipitation for the month.
Soil-moisture storage at the beginning of the month.
Sums of temperature over 30° F. for the month.

Groundwater storage at the end of the month was found to be more closely related to the correction factor than any other variable. The relationship is logical, as GWS-E is a reflection of at least three factors: groundwater storage at the beginning of the month, soil-moisture storage at the beginning of the month, and rainfall for the month, as brought out in the section on groundwater storage estimation.

Groups II and IV were both linearly related to GWS-E, but they had quite different regression coefficients. May and June were troublesome, and it became evident that June should be added to the group II months, while May's relationship was close to that of group IV, but at a lower level.

Group I months, those with low beginning groundwater storage, were not well related to GWS-E. The variation of correction factors within this group was not great, but a multiple regression showed that they were related to monthly rainfall and to monthly temperature. The equation took this form:

$$\text{c.f.} = a + b_1P - b_2T$$

in which:
P=10 x precipitation for month/number of days in month.
T=sum of temperatures over 30° F./number of days in month.

The relationships between the correction factor and storage values were thus established. However, it should be stressed that these storage values must be those estimated from climatic factors and not those determined from hydrographic analysis, which created an apparent impasse: groundwater storage estimates were needed to estimate storage precipitation, but the latter value was used in the estimation of groundwater storage. The problem was resolved by using a preliminary estimate of groundwater storage based on total precipitation values to determine estimated storage precipitation. Estimated storage precipitation was then inserted into all subsequent regressions. These estimates are given in table 8. While the preliminary groundwater estimates were not quite as accurate as their counterparts in which estimated storage precipitation was used, they are accurate enough for the purposes described here.

Actually, the estimation of the correction coefficients does not require great accuracy. Accordingly, graphs were prepared from which the correction factors could be read quickly and without computation (fig. 6).

Figure 7 shows the development of the estimation of storage precipitation in group II months. The abscissa in all four relationships is measured storage precipitation. In figure 7 (A) the relationship is curvilinear because of the excessively high direct

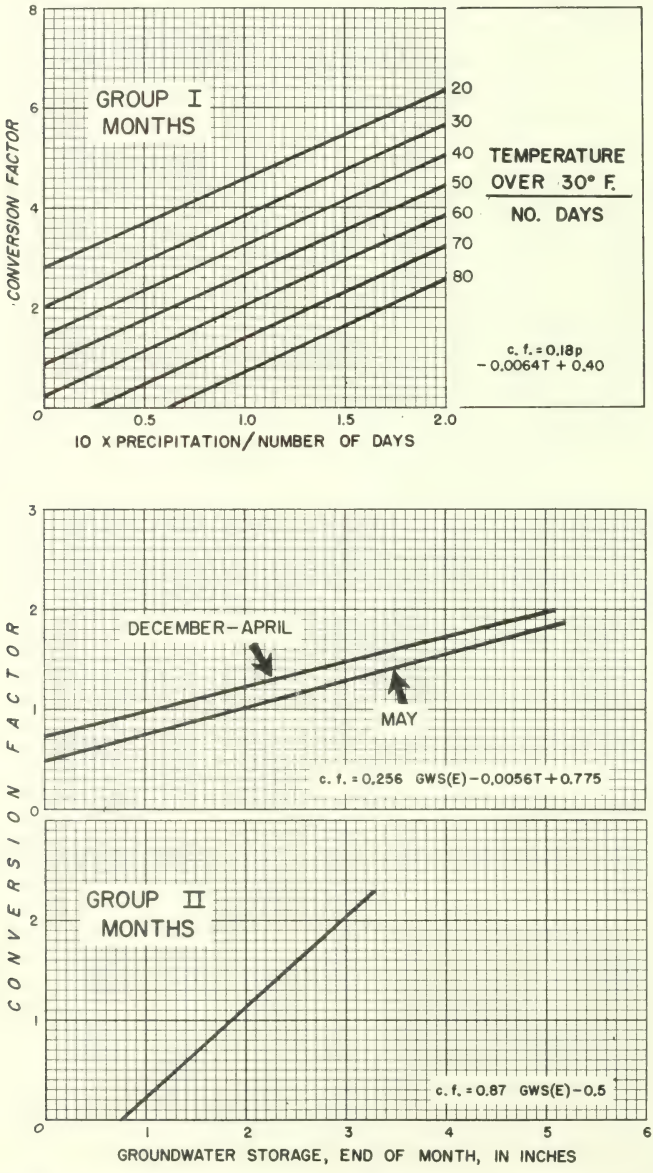

Figure 6. — Monographs for obtaining conversion factors for storage precipitation.

runoff in the months of high rainfall. In figure 7 (B) a linear relationship is obtained by substituting the square root of precipitation, but the scatter is excessive. Figure 7 (C), in which one correction factor was used for all months in the group, still shows an excessive scatter of points, most of which was removed in figure 7 (D).

Basic data for monthly prediction equations are given in table 8.

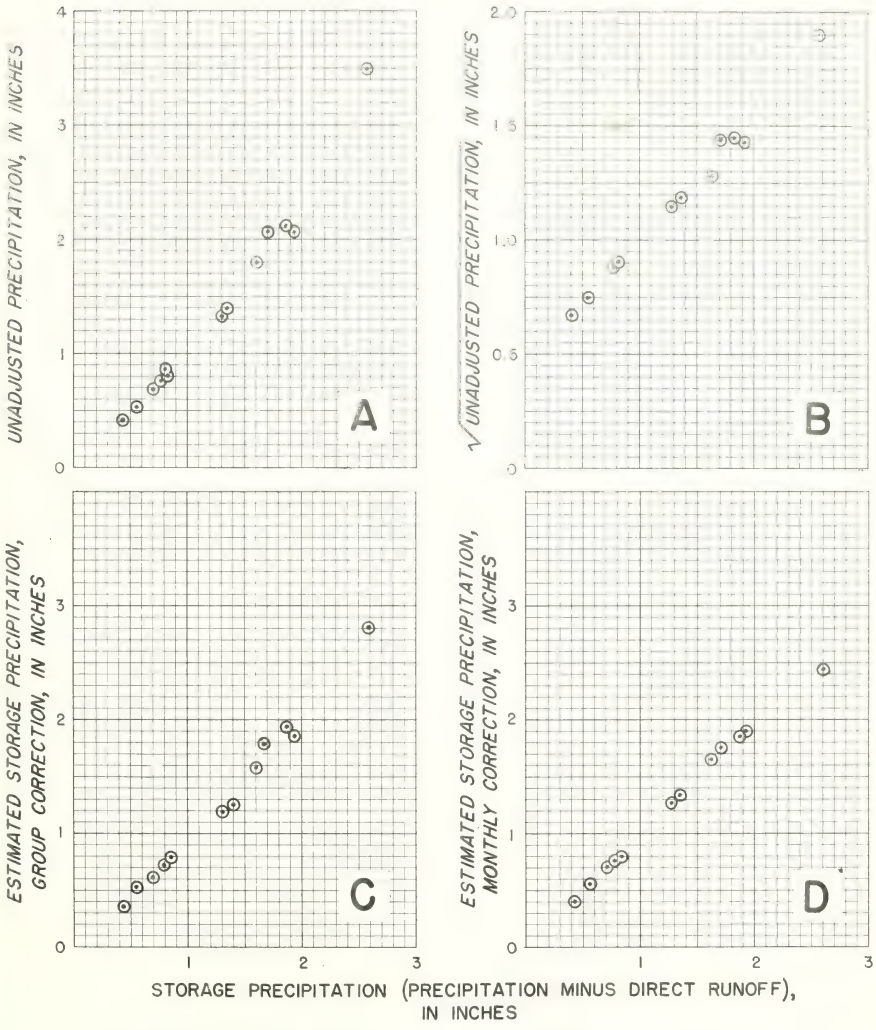

Figure 7. — The evolution of estimated storage precipitation for group II months.

Table 8. — *Basic data and estimates for monthly runoff analysis*

Year and month	Days in month, No.	Precipitation	Runoff	GWS (B)	TS (B)	GWS (E)	TS (E)	Average temp.	Sum of temp. over 30°F./10	Direct runoff	Est. GWS (B)[1]	Est. GWS (B)[2]	Est. GWS (E)[1]	Est. runoff[3]
1949														
April	30	5.23	3.47	2.01	8.96*	3.20	9.80*	44.6	90	0.84	1.82	1.80	3.17	3.13
May	31	7.22	4.91	3.20	9.80*	3.35	9.85*	56.6	165	1.13	3.17	3.09	3.27	4.87
June	30	1.02	1.26	3.35	9.85*	1.38	6.38*	67.1	222	.02	3.27	3.32	1.36	1.27
July	31	4.12	.69	1.38	6.38*	.86	6.36*	71.2	255	.10	1.36	1.27	.88	.75
August	31	6.03	.69	.86	6.36*	.79	7.79*	68.6	240	.25	.88	.85	.77	.61
September	30	4.02	.55	.79	7.79*	1.04	7.96	56.6	159	.13	.77	.86	.85	.58
October	31	2.63	.80	1.04	7.96	1.23	8.54	54.2	150	.10	.85	1.00	1.09	.78
November	30	2.59	1.17	1.23	8.54	1.39	8.46	35.6	51	.15	1.09	1.19	1.47	1.25
December	31	4.04	2.07	1.39	8.46	2.92	9.78	28.0	24	.50	1.47	1.50	2.85	1.99
1950														
May	31	4.35	2.64	2.60	9.74	3.17	10.13	53.0	143	.51	2.63	2.61	2.92	2.66
June	30	3.18	2.14	3.17	10.13	1.76	7.72	62.0	192	.34	2.92	2.99	1.69	2.13
July	31	5.62	1.88	1.76	7.72	1.42	7.33	65.6	220	.57	1.69	1.74	1.28	1.91
August	31	2.25	.76	1.42	7.33	.87	6.29	65.2	218	.10	1.28	1.33	.78	.63
September	30	3.16	.57	.87	6.29	.65	6.98	55.8	155	.06	.78	.81	.65	.57
October	31	2.66	.59	.65	6.98	.79	7.52	51.7	135	.09	.65	.62	.92	.58
1951														
March	31	8.50	5.94	3.46	10.36	5.50	12.64	31.6	29	2.03	3.28	3.37	5.35	5.79
April	30	3.83	5.10	5.50	12.64	3.04	9.46	44.3	87	.70	5.35	5.45	3.09	4.71
May	31	3.17	1.83	3.04	9.46	1.70	8.46	56.4	164	.23	3.09	3.03	2.16	1.82
June	30	4.38	1.40	1.70	8.46	1.58	8.04	62.6	195	.29	2.16	2.11	1.53	1.42
July	31	6.41	1.40	1.58	8.04	1.58	8.57	67.7	234	.45	1.53	1.59	1.37	1.48
August	31	2.50	.88	1.58	8.57	.98	6.62	65.9	222	.07	1.37	1.50	.89	.89
September	30	2.84	.56	.98	6.62	.66	6.64	59.8	178	.06	.89	.93	.62	.59
October	31	4.06	.68	.66	6.64	1.04	8.22	51.0	130	.17	.62	.63	1.00	.71

1952														
April	30	10.26	7.71	3.26	10.05	4.50	11.34	46.3	99	2.55	3.34	3.41	4.80	7.78
May	31	6.33	4.46	4.50	11.34	4.00	10.96	52.4	139	.84	4.80	4.63	3.82	4.47
June	30	2.64	2.48	4.00	10.96	1.68	7.00	65.1	211	.19	3.82	3.86	1.85	2.44
July	31	10.83	5.04	1.68	7.00	1.89	7.13	70.2	250	2.89	1.85	1.85	1.94	5.08
August	31	6.58	2.46	1.89	7.13	1.66	7.75	66.2	224	.76	1.94	1.83	1.71	2.57
September	30	6.21	3.31	1.66	7.75	1.62	7.55	61.5	189	1.11	1.71	1.72	1.69	2.98
October	31	1.41	1.01	1.62	7.55	1.12	7.49	45.2	98	.06	1.69	1.67	1.22	1.13
1953														
January	31	6.14	4.33	2.79	9.47	3.75	10.53	27.4	18	1.26	3.62	3.66	3.79	4.82
February	28	4.06	3.51	3.75	10.53	3.24	9.99	28.2	22	.63	3.79	3.98	3.15	3.67
March	31	5.74	4.45	3.24	9.99	3.80	10.54	33.6	44	.89	3.15	3.21	3.56	4.26
April	30	6.17	4.96	3.80	10.54	3.70	10.55	42.8	80	.84	3.56	3.78	3.65	4.90
May	31	5.36	3.59	3.70	10.55	3.10	10.52	57.8	172	.50	3.65	3.91	3.03	3.63
June	30	2.00	1.77	3.10	10.52	1.96	6.66	65.4	212	.10	3.03	3.08	1.47	1.81
July	31	4.30	.87	1.96	6.66	.90	6.56	69.2	243	.12	1.47	1.48	.92	.90
August	31	1.37	.47	.90	6.56	.50	4.32	67.0	230	.01	.92	.94	.48	.45
September	30	5.26	.60	.50	4.32	.32	6.06	60.8	185	.26	.48	.46	.41	.61
October	31	3.70	.48	.32	6.06	.86	8.36	53.0	143	.14	.41	.40	.88	.46
November	30	3.78	.97	.86	8.36	1.55	8.82	41.3	76	.16	.88	.85	1.45	.94
1954														
February	28	3.93	2.01	1.58	8.43	2.83	9.90	30.0	32	.47	1.78	1.74	3.02	2.03
March	31	4.91	3.71	2.83	9.90	2.92	9.81	31.8	38	.71	3.02	3.15	2.84	4.09
April	30	4.38	3.05	2.92	9.81	2.78	9.92	46.5	108	.59	2.84	2.90	2.65	3.17
May	31	4.21	3.25	2.78	9.92	2.30	9.04	52.8	142	.52	2.65	2.55	2.32	3.26
June	30	1.95	1.15	2.30	9.04	1.18	6.65	64.8	209	.11	2.32	2.27	1.25	1.13
July	31	1.76	.55	1.18	6.65	.73	4.61	67.2	230	.03	1.25	1.23	.77	.55
August	31	6.04	.49	.73	4.61	.38	7.46	65.2	218	.16	.77	.76	.62	.54
September	30	3.27	.37	.38	7.46	.31	6.90	59.6	177	.08	.62	.47	—	.36

[1]Estimated by equations using total precipitation.
[2]Estimated by equations using estimated storage precipitation.
[3]Estimated by equations 7, 8, 9, and 10.
*The soil-moisture portion of this total was estimated.

GWS (B) = Groundwater storage at the beginning of the month.
GWS (E) = Groundwater storage at the end of the month.
TS (B) = Total storage at the beginning of the month.
TS (E) = Total storage at the end of the month.

Water-Loss Equations

Using estimated values of groundwater storage and storage precipitation, water-loss equations were recomputed as follows: December through April—group IV:

[7] $$\text{Water loss} = 1.273 + 0.484_{P_{11}} - 0.668_{S_{11}}$$

May and June—group III:

[8] $$\text{Water loss} = 1.757 - 0.634_{P_{11}} - 5.944_{T_1} + 2.487_{P_{11}T_1} + 3.017_{T_2} - 0.424_{S_{11}}$$

July through November—group II (in which all S_{11} values were 1.00 and above).

[9] $$\text{Water loss} = 0.881_{P_{12}} + 1.894_{T_1} - 0.492_{S_{11}} - 1.256$$

July through November—group I (in which all S_{11} values were below 1.00).

[10] $$\text{Water loss} = 0.996_{P_{13}} + 1.390_{T_1} - 0.512_{S_{11}} - 1.076$$

in which—

P_{11}=30 x daily storage precipitation weighted on 40-basis/sum of weights.

P_{12}=30 x daily storage precipitation weighted on 80-basis/sum of weights.

P_{13}=30 x daily storage precipitation weighted on 4-percent decrease basis/sum of weights.

T_1 =Average monthly length of day, sunrise to sunset, in minutes/1000.

T_2 =Sum of temperatures over 30°F. for month/number of days in month x 100.

S_{11}=Estimated groundwater storage at the beginning of the month (GWS-B), based on storage precipitation data.

As to precision: figure 8 (A) illustrates the relationship between precipitation and runoff for May and June months. Nearly all of the scatter of the points is due to the variation in temperature between individual months and is accounted for by an additional variable in the 5-variable equation. The divergent curves reflect the interaction in the equation.

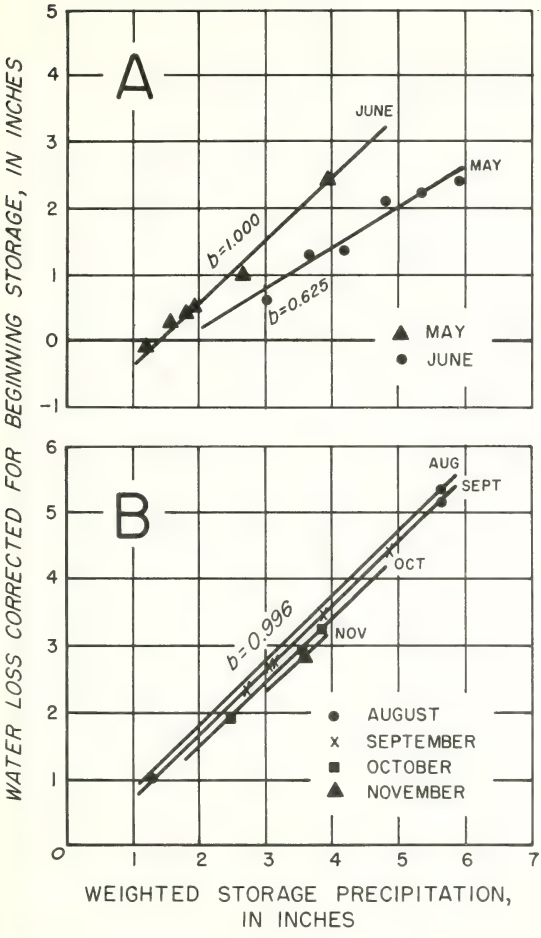

Figure 8.—The relationships between precipitation and runoff for (A) May and June months and (B) group I months — July, August, September, October, November.

Figure 8 (B) shows the relationship between precipitation and water loss for group I months. The family of curves shows the variation due to months. In both figures, actual water loss has been corrected by the calculated effect of the estimated beginning groundwater storage level. Table 9 presents the statistics related to the preceding equations.

Standard errors of estimate and correlation coefficients shown in table 9 indicate the accuracy of the estimating equations; the standard errors are well under 10 percent of mean monthly runoff so that reasonably small changes in water loss or runoff might be detected in a post-calibration period. However, there is no way of knowing if the high correlations are valid, if they are the results of chance, or if they stem from overmanipulation

Table 9. — *Statistics for estimating equations*

Item	Group IV December through April: *Equation 7*	Group III May and June: *Equation 8*	Group II July through November (high GWS-B): *Equation 9*	Group I July through November (low GWS-B): *Equation 10*
Number of samples	12	12	13	12
Degrees of freedom for error	9	6	9	8
$S_{y.x}$ (standard error of estimate)	0.291	0.037	0.136	0.041
Mean water loss	1.41	1.24	2.80	3.26
5 percent of WL	0.070	0.062	0.140	0.163
Correlation coefficient	0.966	0.9996	0.997	0.9996
Mean runoff	4.19	2.57	1.60	0.58
10 percent of runoff	0.419	0.257	0.160	0.058
Correlation coefficient	0.987	0.9998	0.996	0.972

of the data. Tested on a 24-month record of the 4-year period that followed the calibration period, average deviations were 0.34 inch or 16 percent of the average monthly runoff. This, however, as noted before, was an unusual period in which occurred drought, hurricane rainfalls, and a wildfire that burned over about one-third of the watershed.

There has been some question as to the importance of the water-loss estimate. Even though it is a natural phenomenon and may legitimately be used to detect the effects of treatment, most hydrologists and watershed managers are interested in the runoff value. Runoff during the summer months with low groundwater storage (group I months) is particularly important to watershed managers.

If the object of a future analysis is merely to detect differences due to treatment, water-loss analysis should be used because of its greater sensitivity. In any event, water-loss estimates can easily be converted to runoff by subtraction from precipitation. If it were desired to estimate runoff directly, precipitation would have to be weighted oppositely to the weighting procedure used in the storage estimates—another lengthy operation—and direct runoff would have to be a separate variable.

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The Location Decision for Wood-Using Industries

In the Northern Appalachians

by

Perry R. Hagenstein

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The Location Decision for Wood-Using Industries

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Introduction

CHOOSING a site for an industrial plant requires a major decision, a decision in which many factors must be considered. In this decision-making process the economist can make a contribution. He can identify the most important factors to be considered; he can describe the decision-making process; and he can provide the kind of economic information that the decision-maker needs. He can help industrial firms and industrial development agencies to evaluate alternative locations for industrial plants; and he can suggest ways in which development agencies can facilitate and promote the establishment of new plants.

This economic-analysis approach was applied to the wood-using industries in a study made recently by the Northeastern Forest

Experiment Station. The purpose of the study was to provide a better understanding of the decision-making process, and a guide that can be used by selected wood-using industries in evaluating alternative mill locations.

Four wood-using industries were considered in the study: the lumber, particle-board, woodpulp, and furniture industries. Other wood-using industries were considered, but these four were chosen for study because they represent an interesting range of alternatives. Each uses a different type of raw wood material. The capital investment required for average size plants ranges from a modest amount in the lumber industry to a very large amount in the woodpulp industry. The range of alternatives covers a major part of the range of the whole wood-using industry.

Three of the industries chosen for study — lumber, particle-board, and woodpulp — are considered *primary* wood-using industries because they use round wood as their raw material. The fourth — the furniture industry — is considered a *secondary* wood-using industry because it uses lumber as its raw material.

Geographically, the study was restricted to the northern Appalachian region. This is an important hardwood-producing area. Furthermore, it is an underdeveloped area, in which the forest resources offer opportunities for increased economic development (Perloff and others 1960). The scope of the study was restricted to consideration of only the production side of the overall location decision.

A study of the likelihood of a specific type of industrial plant locating in a specific area requires more than an analysis of the availability of particular requirements in that area. It also requires an analysis of potential markets for the plant's output and a comparison of the area with all other possible locations — both important considerations, but beyond the scope of this study.

The material used in this report was obtained in a series of interviews with executives of firms in the industries under consideration. The interviews were directed at identifying factors that affect the location decision and at obtaining (1) estimates of the physical quantities of inputs required for plants of specified sizes and (2) comparisons of the costs of these inputs with those incurred by other plants in the region.

Within each industry, certain restrictions were placed on the scope of the study. The great preponderance of hardwoods in the Appalachian area limits the types of wood-using industry that can be considered. The hardwood resource restricts a sawmill to producing mostly hardwood lumber and a particle-board plant to producing a board made wholly or largely of hardwood particles. For a pulpmill, the hardwood resource limits the type of pulping processes that can be used satisfactorily. The neutral sulfite semi-chemical process was chosen as being well adapted to the pulping of Appalachian hardwoods.

Restrictions were also placed on the size of facilities selected for examination — a selection based on current construction in these industries. In the sawmill industry in the northern Appalachian area, modern sawmills are generally constructed to produce 10,000 to 50,000 board feet of lumber per day; and consideration here was directed at mills producing about 20,000 board feet. For particle-board plants, the size considered in this study is about 20,000,000 square feet (¾-inch base) of production per year, which is the minimum efficient size today for independent plants. For pulpmills, discussions with industry personnel suggested that the minimum efficient size of new mills is generally about 200 tons per day. And an average size for new wooden furniture plants appeared to be about $5,000,000 in annual sales.

The Location Decision

The decision to locate an industrial plant on a particular site or in a particular area depends on a number of factors. Some are economic, such as the cost of materials, labor, and transporting the finished product to market (Hoover 1948, Isard 1956, Greenhut 1956, and Lösch 1954). Other factors that affect the location decision apparently have no substantial economic basis; for example, the presence of churches, schools, recreation facilities, and other amenities (Thompson 1961, Mueller and others 1961). However, a common consideration about the factors affecting location is that the available quantities, the costs, or the decision-

maker's judgment concerning their suitability will vary among locations.

Demand aspects may also be important. First, demand for a product usually triggers the location decision. This is especially true in industries with expanding markets. However, it may also be true in industries where the total demand is constant but where changes are occurring in the location of markets. Second, there are often strategic considerations in locating to meet the demand for certain products (Hotelling 1929, Smithies 1941, Ackley 1942, and Stevens 1961). For example, direct contact with buyers and immediate delivery are important factors in some industries.

The location decision is often the most important single decision ever made by a firm. Because industrial plants are relatively immobile, the firm commits itself to a given location for a long time when it undertakes construction of a new plant. In addition, firms can and do affect their cost and profit structures strikingly in making the location decision because revenues, and especially costs, may vary substantially among locations.

The manner in which firms make the location decision varies; however, some useful generalizations can be made. A triggering mechanism is generally required; the scope of the choice must be brought down to manageable proportions; the costs and financial returns from the various possible locations must be considered; and the non-economic factors that affect location must be taken into account.

The nature of the location decision and the method of making it differ among the four wood-using industries considered in this study. These differences are important in that they affect the likelihood of plants being located in particular areas, and thus they may substantially affect the strategies employed by industrial-development agencies. Differences in the method of making the location decision are the result of differences in the size of plants in the various industries, in the competitive conditions within each industry, in the nature of the raw material that will be used, and in the nature of the markets that will be entered. Of these factors, size of plant is the most important. Two general types of location decision can be distinguished on the basis of plant size: the small plant and the large plant.

THE SMALL PLANT

Sawmills and those particle-board plants that are tied to specific sources of residues for raw materials fall into the small category. Some small furniture plants and other small wood-using plants not specifically studied (charcoal, pallets, handles) are also included in this class. Small wood-using plants are often developed by one or two local entrepreneurs who have some experience in or knowledge of a particular industry. Such entrepreneurial talent is often local in the sense that it is likely to be used in developing a hometown enterprise but is wholly unlikely to be used elsewhere.

It can be argued that there is an economic basis for this so-called hometown preference: knowledge of the area and business contacts may be important to the economic well-being of the firm; and knowledge of a local raw-material supply in the area may be important to wood-using firms. Choice of location as a result of hometown preference can also be considered as an example of historical accident.[1] This appears to be true of many small plants.

In the first step of the location decision, the choice of location is made. The actual choice of the locality, and often even the site, for a new plant is made prior to the final decision to build a new plant. For an enterprise tied to a specific source of raw material, the location of the raw material determines the location of the plant. In other cases, the choice is a matter simply of the entrepreneur's preference — before even the decision as to whether or not a plant will actually be built has been made.

In the second step — after the *where* decision has been made — the decision-maker considers the type of product that can be produced. This is determined mainly by the raw materials that are available. Consideration is given next to the markets available for the various possible products. Estimated production costs and estimated returns for the various product and market alternatives are compared.

[1] Location by historical accident is not an uncommon occurrence in numerous industries. Although individual plants are resistant to change of location, in general it can be expected that the force of competition will lead to a reasonable location pattern. As Hoover pointed out (1948): "Competition, insofar as it prevails, will reward and encourage well-located enterprises and shorten the lives of poorly located ones."

In the final step, the decision to build or not to build a plant is made. The decision made in this step is an economic decision; profits are the major criterion. For small plants the actual choice of location is generally based on non-economic criteria; economic criteria are used only in deciding whether or not to build a plant.

THE LARGE PLANT

Pulpmills, medium and large furniture plants, and those particle-board plants that are not tied to specific sources of residues fall into the large category. The location decision for large wood-using plants approximates that presented in standard texts on economic location (Hoover 1948 and Isard 1956). Today most large plants are associated with large firms, which are not generally tied to particular localities. Thus the choice of location can be based on an evaluation of several alternative locations.

After the choice has been made, managerial talent can be transported to the location; and knowledge of the local area, if it is necessary, can be purchased. Thus in making the location decision the large firm is usually free of the constraints associated with hometown preference (Mueller and Morgan 1962). On the other hand — and this may be of special importance for wood-using industries — the large firm is generally faced with the prospect of moving managerial employees to the area of the new location. Considerations of this sort are often important enough to remove the location decision from the realm of pure and rational economics to that limbo where decisions are said to be *profit-satisficing*[2] rather than *profit maximizing.* In either event, the choice is made among alternative locations in the following manner.

The first consideration is markets. This factor is the one that usually triggers the initial investigation of the location decision. Several aspects of the markets may be important. The firm is likely to consider the location of the markets and the type of product that will compete best in the various markets. In addition, it will consider whether entry into or expansion in various

[2] *Profit-satisficing* means a willingness to settle for a profit that is satisfactory in the circumstances even though it may be less than the maximum possible. This concept is generally attributed to Herbert A. Simon (March and Simon 1958).

markets will enable the firm to meet particular goals such as maintenance of market shares and product diversification. Estimates are made of revenues likely to be obtained in the various markets.

The second consideration is the product itself, and the production process to be used. The firm often has some latitude in choice of process once the product has been determined.

The third consideration is the cost of production at alternative plant locations. Estimates are made of the availability and cost of the required inputs at various locations.

In the final consideration, the firm makes its choice among alternative locations, using profitability as the major criterion. But it is at this point that non-economic considerations may place certain constraints on the choice of location. If these considerations are important, it can be said that the firm is making a profit-satisficing decision rather than a profit-maximizing decision, as described by Hans H. Jenny (Boulding and Spivey 1960).

Factors that Affect the Decision

The four wood-using industries examined here differ considerably with respect to the location decision. They all require wood as a raw material, but the type and form of the wood each requires are different. Investment required ranges from small to very large. The four industries differ in the type of markets in which their products are sold. And they represent a range of opportunities for investment and for analysis.

Differences between the ways in which small and large firms make their location decisions have already been discussed. There are also differences among the industries — especially in the relative importance of the various factors that affect the location decision and in the amount of each input required for a plant. These differences, both in relative importance of location factors and in quantities of inputs required, have a substantial bearing on evaluations of particular locations by industrial-development agencies.

In evaluating various alternative locations, the individual firm has its own basis for making comparisons. The firm has considerable knowledge of its requirements; it can generally obtain the information it needs about the availability and cost of its requirements at alternative locations. On the other hand, simultaneous comparisons of alternative locations and alternative industries are usually made by outside organizations. Not only must these organizations be able to obtain information regarding requirements in various industries, but they must also have some common basis for evaluating locations.

ASSUMPTIONS

To provide comparable information on requirements for the four wood-using industries in the northern Appalachians, certain assumptions were made. The first assumption concerns the units in which location requirements will be expressed. The usual accounting practice of wood-using firms is to express cost items in dollars per sales unit: per thousand board feet of lumber, per thousand square feet of particle board, or per ton of pulp.

On the other hand, in considering differences between locations, the figures available to the firm are normally expressed in terms of the units by which the inputs are sold: electricity in kilowatt hours, labor in hourly or daily wages, wood in thousand board feet or cords, forest land in acres. For this study, requirements are expressed in the latter terms — the units by which these items are bought by the wood-using firm — because these are the terms that the author believes will be most useful in making evaluations of alternative locations.

For most location requirements, the quantity can be expressed in familiar terms. Thus there is no problem in saying what the quantity requirements are for a plant of a particular type and size. On the other hand, if the factors that affect location are to be evaluated in terms of their relative impact, some further assumptions are required to place these factors on a common basis. The general procedure used here is to convert requirements to a daily basis so that comparisons can be made.

Forest land and industrial sites are the two major location factors that generally require capital expenditures. The basic

Table 1.—*Assumptions about average plants in four wood-using industries*

Item	Lumber	Particle board	Woodpulp	Furniture
		OUTPUT		
1. Size of plant:	20,000 bd. ft. of lumber per day (5,000,000 bd. ft. per year)	20,000,000 sq. ft. (¾-inch basis) per year.	200 tons per day.	Annual sales of $5,000,000.
2. Type of output:	Rough, air-dry graded hardwood lumber.	Medium-quality flakeboard made largely of hardwood particles.	Neutral-sulfite semichemical pulp made largely from hardwoods.	Medium-quality wooden furniture (case goods).
		OPERATING RATES		
1. Days per year:	250	300	325	275
2. Hours per day:	8	22	24	8
		CAPITAL EXPENDITURES		
1. Forest land:	Forest land is assumed to be leased at an annual cost of $0.75 per acre, or 10 percent of the average selling price of forest land, excluding timber, in the northern Appalachians. This leasing cost covers annual property taxes of $0.30 per acre and allows for an alternative rate of return of 6 percent to the landowner. Forest land is not required for furniture plants.			
2. Industrial site:	Industrial sites are treated as though they are leased. The annual cost of leasing is assumed to be equal to 15 percent of the average selling price of industrial sites.			
3. Amount of loans available under local financial-assistance plans:	$10,000	$120,000	$350,000	$200,000
		SELLING PRICE		
Selling price per unit of product:	$90 per 1,000 bd. ft. of lumber.	$130 per 1,000 sq. ft. (¾-inch basis) of lumber.	$140 per ton of woodpulp.	No definable units.

assumption made in this study was that land and sites are leased instead of purchased outright. If it is assumed that they are leased, then the annual lease payments can be considered current costs and little violence is done to the evaluations of relative importance.

Some assumptions must also be made about the cost of borrowing funds, because financial-assistance plans are now commonly a part of the inducement package offered by industrial-development agencies. The market for borrowed funds in the United States is largely a national market; thus interest rates will tend to be similar among various locations because of the mobility of capital and the tendency for interest rates to equalize on loans of similar potential. However, there may be differences in interest rates among industries because of differences in size of firms and risk associated with investments in the various industries.

The one important exception to the general rule that interest rates do not vary with location is provided by the local financial-assistance plans. Two of these financial-assistance plans for states in the region with which this study is concerned provide for loans of public funds to cover one-half the cost of industrial sites and buildings for new industrial plants. As a practical matter, these loans do not run over $1,000,000 for the largest plants, and the interest rate presently being charged on these public loans is about 2 percent.

The assumptions concerning output, operating rates, capital expenditures, and product selling price are outlined in table 1.

LOCATION REQUIREMENTS

The location requirements considered in making an economic location decision are those inputs that vary in price among locations — raw materials, labor, power, and others. Major items that do not vary in price from location to location are selling expense, machinery costs, and general overhead.

There are also differences in the type of inputs and quantities required in the various industries. For example, operators of pulpmills require their wood in the form of pulpwood, but the furniture industry people want theirs in the form of lumber. In addi-

tion, within a given industry it is generally possible to substitute among inputs to some extent — for instance, materials-handling equipment and labor are substitutable to a degree.

The time when the location decision is made is also the time when there is the greatest degree of freedom in choosing a process or method of production. Once a plant or production line has been built, the cost of changing to allow for a more capital-intensive method of production is likely to be higher than at the time the location decision was made. As a result, firms exercise care in choosing the most efficient processes available at the time of the location decision.

There is general agreement in an industry at any point in time that a particular process is most efficient. This is true because information flows rather freely within these industries through personal contacts, trade journals, and technical assistance provided by machinery manufacturers, government agencies, and industry trade associations. Therefore, necessary inputs for any new plant in an industry are about the same from plant to plant. This is particularly true for a fixed output — that is, when plant size is held constant.

The location requirements considered in this study are for plants of a particular size and type. They are for average plants, based on current practices in the northern Appalachians. A change in the type of output or size of plant would necessarily involve a change in inputs. A change in the type of output would also probably require a moderate change in the type of inputs, but would involve little change in the quantity required. And a change in the quantity of output would probably require a nearly proportional change in the quantity of inputs.

The specific requirements for plants in all four industries are listed in a common table (table 2). The discussion of each industry, which follows, is limited to considerations not described in the table.

Lumber

Most of the new sawmills in the northern Appalachians are of moderate size (Simmons 1958, p. 26). Sawmills of this type are rather adaptable, and can be used to process a variety of log sizes.

Table 2.—*Factors that affect the location decision for four wood-using industries*

Item	Lumber	Particle board	Woodpulp	Furniture
		INDUSTRY STATUS		
1. Growth trend of industry:	1. Stable.	1. Rapid growth.	1. Moderate growth.	1. Moderate growth.
2. Factors triggering location decision:	1. Production cost squeeze at present location.	1. Expanding markets.	1. Expanding markets.	1. Production cost squeeze at present location.
	2. Unused resource or entrepreneurial talent.	2. Availability of unused wood residues from primary or secondary wood-using plant.		2. Expanding markets.
		STAGES IN MAKING THE LOCATION DECISION		
1. Stages:	1. Location determined largely on basis of home-town preference and local business ties in case of lumber, and on basis of location of raw materials for particle-board plants utilizing particular supplies of wood residues. 2. Type of product that can be produced determined largely by the nature of the available raw material. 3. Available markets considered. 4. Decision made to build a new plant. Size and type of production facilities determined.		1. Availability of expanding markets considered, markets chosen on basis of growth potential and strategic advantage to firm in maintaining or changing relative market shares. Typical for particle-board plants not tied to a specific supply of wood residues, for all woodpulp plants, and for moderate and large furniture plants. 2. Size and type of production facilities chosen to enable firm to compete in market determined in Step 1. 3. Availability and cost of necessary inputs at alternative locations determined.	

4. Choice made among alternative locations on basis of cost and revenue considerations.

	INPUT REQUIREMENTS			
1. Inputs that vary in cost among locations:	1. Logs—20,000 board feet per day.	1. Wood (either residues or roundwood)—75 cords per day.	1. Pulpwood—280 cords per day.	1. Lumber—14,500 board feet per day.
	2. Labor— 3 skilled 5 semiskilled 4 unskilled	2. Labor— 35 skilled 35 semiskilled 30 unskilled	2. Labor— 32 skilled 16 semiskilled 16 unskilled	2. Labor— 75 skilled 150 semiskilled 75 unskilled
	3. Forest land—10,000 acres where competition for timber is strong; none where competition for timber is slight.	3. Forest land—10,000 acres in areas where competition for timber is strong; none where competition for timber is slight.	3. Forest land—30,000 acres where competition is strong or where a particular species is required; none where competition for pulpwood is slight.	3. Forest land—none.
	4. Electricity—750 kwh. per day.	4. Electricity—15,500 kwh. per day.	4. Electricity—55,000 kwh. per day.	4. Electricity—5,800 kwh. per day.
	5. Transportation—highway connections required.	5. Transportation—highway connections; rail connections for noncaptive plants.	5. Transportation—rail and highway connections required.	5. Transportation—rail and highway connections required.
	6. Industrial site—20 acres.	6. Industrial site—20 acres.	6. Industrial site—100 acres.	6. Industrial site—20 acres.
	7. Plant and equipment—$150,000.	7. Plant and equipment—$2,500,000.	7. Plant and equipment—$10,000,000.	7. Plant and equipment—$2,500,000.

(CONTINUED)

Table 2.—(Continued)

Item	Lumber	Particle board	Woodpulp	Furniture
			8. Water—8 million gallons per day required for production. Site on a river usually required for waste disposal; quantity of water required for disposal varies depending on regulation by water commissions and nature of streamflow.	8. Particle board—7300 square feet per day.
2. Inputs that do not vary in cost among locations:	—	Resin—16,800 pounds per day.	1. Sulfur—20 tons per day. 2. Soda ash—75 tons per day. 3. Chlorine—45 tons per day. 4. Caustic soda—18 tons per day.	

They can also be used for various types of output, such as lumber or dimension stock. Emphasis can also be placed on the production of large quantities of lumber — sacrificing quality — or on the production of high-quality lumber — sacrificing quantity. Because sawmills are adaptable, they are located in a wide variety of forest resource-conditions, ranging from heavily forested areas to primarily agricultural areas.

Once the tentative location for a sawmill has been chosen, the species and quality of the available timber are important considerations in determining the markets that will be entered. Species and grades that bring high prices can be shipped to more distant markets than those that bring low prices.

Markets for hardwood lumber for particular uses are to a large extent restricted geographically. In addition, particular uses often require certain species or grades of lumber. Thus, the High Point area of North Carolina, a major center for furniture manufacture, is a primary market for the better grades of cherry, birch, maple, walnut, and yellow-poplar. Oak of the lower grades is used extensively in the flooring and pallet industries, and nearly any species or grade of hardwood can be used for industrial purposes such as industrial blocking or dunnage. Flooring production is localized to some extent in the hardwood lumber-producing areas, but the major markets for pallets and industrial lumber are found in areas of concentrated manufacturing and shipping — in the Pittsburgh-Youngstown area or other nearby manufacturing cities, and in port cities.

Lumber producers in the northern Appalachians generally produce some mixture of high- and low-quality lumber. Producers who aim for low-quality markets usually find a ready market for the high-quality lumber that they produce almost as a byproduct. For them, markets for high-grade lumber are not of prime importance in determining a mill location. On the other hand, low-quality lumber produced as a byproduct by producers who aim for high-quality markets often presents a real problem. For them, markets for this low-quality byproduct may be very important in determining mill location.

By holding forest land, sawmill operators in some areas attempt to guarantee themselves a supply of raw material and to

obtain some control over timber prices. This is generally done in areas where there is considerable competition for timber. But in parts of the northern Appalachians where there is little competition and where agriculture is of some importance, this is not generally necessary. In such areas, it was found that single operators could exert monopsony power over stumpage prices without owning forest land.

The size of forest holdings desired by sawmill owners depends on the severity of competition for stumpage in the area of the sawmill. One respondent said he would like to own enough land to supply all of his raw material; however, he actually owns only 20 percent of the forest area necessary to meet all of his needs. Other respondents in areas where owning land is considered a requirement for operating a moderate-size sawmill suggested that enough land to supply one-third of the raw-material requirements would be sufficient. These respondents also had enough land to supply 20 percent of their needs.

The modern sawmill examined in this study is relatively efficient in terms of output per unit of labor. Labor productivity is considerably higher in the modern sawmill than in the average mill now located in the study area. Thus, to assess the impact on employment of expanded lumber production in an area, the use of current average labor-productivity rates in the area is likely to lead to overestimates.

Particle Board

There are two general types of particle-board plants: those that use roundwood as raw material and those that use wood residues. The type of raw material that is used has an important effect on both the type of particle board produced and the markets in which the board will compete. A brief description of both types follows.

For plants using wood residues, the type of board that is produced is determined to a large extent by the available residues. In general, both the cost of production and the quality of boards produced from residues are lower than those for boards produced from roundwood. The fact that there are no raw-material costs is an important factor in lowering costs. At worst, there may be a

replacement cost for the fuel required to replace residues formerly used for fuel.

The species composition of the available residues is usually the most important factor restricting the quality of this type of particle board. The high-quality boards are produced from light-weight and light-colored species. Much of the residues available in the northern Appalachians are heavy, and some produce a dark board of lower quality. Quality is also restricted to some extent by the form of the residues, although some of the technical problems of this nature are being overcome through advances in equipment design.

Largely because of the lower value of these boards — and partly because of the usually greater weight, which affects shipping costs — these boards normally sell in localized markets. Maximum shipping distances range from 150 to 250 miles. These boards tend to compete on a price basis rather than a quality basis, although minimum quality standards must be met.

Producers who are not tied to a source of waste for raw material have generally settled on the production of a homogeneous or three-layer flakeboard made of light-weight woods. Such boards are generally of high quality; they tend to compete with each other on a quality basis rather than on a price basis. They are distributed over a broad market area to shipping distances that may be 1,000 miles or more. Pine and soft hardwoods are the preferred species for production of this type of board. Wood is commonly purchased as pulpwood. A multi-platen press operation is generally employed by such producers.

The major market for particle board is the furniture and cabinet industry. Competition within the particle-board industry in recent years has resulted in a shift toward the production of a more finished product. Particle-board producers are competing for these markets by providing such services as cutting-to-size, prefinishing, and even laminating and veneering their product before it leaves the plant.

In the same way that sawmill owners like to own forest land in areas where competition for stumpage is strong, particle-board producers also require forest holdings capable of supplying probably one-third of the total requirements of the plant in areas

where competition for timber is strong. For a supply of hardwood, owning forest land is not considered an important factor in this region; however, if the particle board is to be made from pine or other softwoods, competition for raw material will be strong and forest-land holdings can be considered a requirement.

Resin costs make up an important part of the total cost of producing particle board. However, resin costs have little or no effect on the location decision for particle-board plants in the Northeast because resin prices are standardized among producers and are quoted on a delivered basis. Resin costs might be an important factor elsewhere and would undoubtedly become important if the pricing system for resin were to change.

Woodpulp

Location requirements for pulpmills generally are restrictive in the sense that large quantities of each input are required. Location requirements are also restrictive in the sense that a mill is generally planned for producing a specific product or products for a particular market. Of course, changes in output may be made after the mill is in operation; but in the planning stages, and in construction, design is generally predicated on a specific output.

In this study, we considered only factors that affect the location of pulpmills. However, most of the pulping facilities built in the United States today are built as part of an integrated pulp- and paper-making plant. This leads to a minor degree of confusion, particularly with respect to markets and transportation costs for woodpulp.

Clearly, the chief market for woodpulp produced in an integrated plant is the paper mill right next door, and the cost of transporting the pulp to the paper mill is slight. However, in choosing a location for an integrated facility, the transportation costs considered by the decision-maker will be those for transporting the paper to its markets. Because transportation requirements are an important location factor, it will be assumed that transportation requirements for paper are an accurate measure of the transportation requirements for woodpulp.

The markets in which paper is sold are national in scope. To a large extent they coincide with the pattern of population distribu-

tion, although markets for certain grades of paper may be restricted geographically. The probable markets for new paper mills in the northern Appalachians would be in the population centers of the Atlantic Seaboard and the North Central States. Mills are generally constructed to produce a relatively narrow range of products; such items as newsprint, book papers, and writing papers are normally produced in different mills. Some of the larger companies in the paper industry produce many of these items; other companies may concentrate on one or two particular items. Market considerations in the location decision depend on the type of paper to be produced.

The choice of the pulping process and the qualities desired in the pulp and the resulting paper determine the selection of tree species that will be used. In considering the Appalachian hardwood region, any pulpmill must plan on using a high percentage of hardwoods and must choose a hardwood pulping process. Today only a few minor hardwood species are considered wholly unsuitable for pulping. However, most papers contain a softwood pulp component—about 20 percent or more of the total—and, as a result, either softwood trees for pulping or softwood market pulp to provide this component is a requirement for most mills.

The desire and need to hold forest land is stronger among pulp producers than among lumber or particle-board producers. Interruptions in the supply of wood to sawmills and particle-board plants are inconvenient. But for the pulpmill, which has a high operating rate necessary to maintain profit levels, an interruption in wood supply can be critical. Holding forest land provides some guarantee of a future wood supply and provides for some monopsony control over pulpwood prices. Having company-owned timber may enable a pulp company to withstand collusion on the part of pulpwood producers.

Most respondents in this study said that their companies would like to be able to supply one-third to one-half of their total wood requirements from company lands. However, in the Eastern hardwood region, the growth of hardwoods meeting pulpwood specifications far exceeds the present drain, and companies locating pulpmills generally are aware of this. Respondents in this study said that the question of forest-land ownership would not be

crucial in most hardwood areas, especially where their wood-procurement areas would not seriously overlap those of other pulpmills.

A pulpmill must have good highway and rail connections. Much of the pulpwood in the Eastern region is hauled by trucks, but many pulpmills also rely on rail shipments for some pulpwood. Where a particular species is needed, such as a softwood component for the pulp, location on rail lines that will allow one-line or two-line hauls from the pulpwood supply area is of importance. This is the case in much of the eastern hardwood region. Rail and highway connections are also important in shipping the final product. Ideally, the pulpmill should be located so that as much of the final product as possible can go to market on one-line or two-line hauls. This may mean locating on major railroad systems and may mean locating so that the mill would be served directly by two or more lines.

Large quantities of water are required in pulp manufacture; and for most types of woodpulp production even larger quantities of water are required for diluting waste material. In some places, water-supply and waste-disposal problems have assumed top priority in determining pulpmill locations. The quality of water required for production of neutral-sulfite semichemical pulp depends on whether or not the pulp is to be bleached. If unbleached pulp is to be used, the requirements are not very restrictive; and many of the rivers in the East have water that is suitable for unbleached pulp manufacture after passing through a settling basin. On the other hand, if the pulp is to be bleached, requirements are much more restrictive; and filter plants, which may cost up to a million dollars, may be required.

In the semichemical pulping processes, no fully satisfactory means of reclaiming chemicals has been developed; consequently, disposal of large quantities of waste liquor is necessary. And to complicate the problem, public pressure to do something about water pollution has become increasingly urgent, and in recent years has resulted in numerous state laws, interstate regulations, and commissions that forbid or penalize water pollution of certain degrees or varieties.

Requirements for industrial sites suitable for a pulpmill are

more restrictive than requirements for sawmills or particle-board plants. Because of the water-supply and waste-disposal problem, the location must be on a river with sufficient low-water flows to meet water-supply and disposal needs. The site must be reasonably level and large enough to provide for good storage and future expansion and have suitable transportation and power facilities. A 50-acre site would be adequate for a 200-tons-per-day mill, but would not be large enough to allow for much expansion; nor would it provide the buffer zone that might be considered necessary under crowded conditions. A 200-acre site would probably be more suitable.

As resin does for particle-board plants, chemicals for pulpmills make up an important part of the total raw material costs; yet these costs do not vary substantially among locations. Prices for the standard chemicals used in woodpulp production appear to be equalized among the various chemical-producing companies. In addition, freight is equalized up to certain amounts for a number of producing and shipping points in the Northeast. Thus, in effect, the chemical producers absorb differences in freight costs; the extent to which freight costs are equalized enables most locations in the Northeast to compete on almost even footing with regard to the cost of chemicals—with the exception of sulfur.

Sulfur is produced along the Gulf Coast in Texas and Louisiana, and prices quoted by sulfur-producing companies in this area are standard. However, freight rates to Eastern users vary somewhat by location. The other three chemicals used by Eastern pulpmills —soda ash, chlorine, and caustic soda—are produced mainly in Michigan and Ohio. Prices on these are equalized, as are most freight rates. Thus chemical costs have only a slight effect on the location decision.

Wooden Furniture

The wooden furniture — "case goods" — industry differs considerably from the three primary wood-using industries discussed. The furniture industry is a *secondary* wood-using industry: it produces consumer goods rather than industrial goods. In fact, of all the major wood-using industries, the furniture industry is perhaps the most strongly oriented toward the consumer. Some

of the other secondary wood-using industries—such as the flooring, pallet, and wooden-container industries — fall in between those that are strongly oriented toward the consumer and those that are strongly oriented toward raw materials. Thus the furniture industry is almost in a class by itself.

The concept of the "average" plant is more elusive for the furniture industry than for the other industries that have been considered. There are two reasons for this: first, there is more variation in types and sizes of plants; second, there is no standard unit of production such as there is in each of the other three industries.

Furniture is purchased at the retail level through a large number of furniture stores, department stores, and mail-order houses. Contact between the retail seller of furniture and the producer is made to a large extent at the furniture "markets," where furniture is exhibited either semi-annually or quarterly. The most important market exhibit for manufacturers in the Appalachian region is held at High Point, North Carolina. Here each producer exhibits a number of style lines. The retailer chooses among these and places orders. The producer then uses the orders in scheduling production runs (Davis 1957). The market provides an opportunity for the producer to keep up with changes in style, production methods, and marketing. Thus it helps him to decide on style lines.

The impact of style and style changes on the location and structure of the furniture industry is important. Because tooling costs are low, styles can be changed readily. Style changes are frequent, and the producer that does not respond readily to these changes may suffer a loss in sales. The ease of making style changes and the frequency with which they are made have had important effects on the industry. No manufacturer can hope to capture a market for very long simply on the basis of style; successful styles can be copied and manufactured readily. One important result is that contact with other manufacturers is necessary so that a firm can keep up with changes. This has led to spatial concentration of the industry.

Entry into the industry is relatively unrestricted, because capital investment in a new plant can be rather small. As a result, the

case-goods industry is fragmented into a large number of firms. There are some cost advantages associated with large-scale production, but manufacturing-cost advantages to be obtained through large-scale production are limited to a large extent by the frequency of style changes (Davis 1957).

Furniture plants vary considerably in size. Small plants, which are essentially craft shops, may employ fewer than 10 production workers and have sales of less than $100,000 annually. The largest plants in the industry have more than 1,000 production workers and sales may run over $50,000,000 annually. There is no minimum profitable size, but small plants are generally less profitable.

In 1960, after-tax profits — as a percent of sales for the industry — varied from a loss of about 2 percent for a sales volume of less than $500,000 to a profit of about 2 percent for a sales volume of $5,000,000 to $10,000,000 and to a profit of about 4 percent for a sales volume over $25,000,000. Based on the above figures, it seems likely that annual sales of $3,000,000 to $5,000,000 would be required to give a reasonable chance for making suitable profits. Capital requirements for furniture plants average about one-half of annual sales.

The quality of furniture that is produced depends primarily on two factors — labor and wood. Labor costs, as a percent of total manufacturer's price, are higher for high-quality furniture than for low-quality furniture. Wood costs per unit of furniture are also higher for high-quality furniture; better species and higher quality lumber are required. Species such as walnut, mahogany, and cherry are generally associated with high-quality furniture, although hidden parts are commonly made of yellow-poplar, gum, or other relatively inexpensive woods.

Because of the variety of wood species used in furniture manufacture, the source of wood is geographically broad. Cherry comes primarily from Pennsylvania, walnut from Indiana, yellow-poplar from the Appalachian region, gum from the Mississippi Delta, and mahogany from overseas. A good deal of substitution is possible among species; for example, yellow-poplar and gum or tupelo are substitutes in some uses. For some species and at particular times, however, style may necessitate use of a certain

species, especially for visible parts. One result of changes in style and substitutability of species is that furniture producers are not strongly tied to a particular geographic source of wood.

Higher labor costs for better quality furniture are a reflection both of more time spent in the manufacturing process and higher levels of skill. Furniture requires more hand labor than many other products. Up to 50 percent of the labor in a plant may be classed as skilled if the quality of the product is high, and nearly all plants require at least 25 percent skilled labor.

Labor skilled in the manufacture of furniture is not necessarily skilled in other manufacturing processes. As a result, the use of standard skill classifications to judge the suitability of a labor supply may be misleading. Skilled labor for the furniture industry is generally found in areas where furniture manufacturing is concentrated. Some say that the best location for a new plant is next to a competitor's plant, in order to attract some of his labor. Skills can be developed, but training takes 6 months to a year or more. And the cost of obtaining skilled labor, or training all labor, may be prohibitive for firms moving into an area where there are no furniture plants.

Relative Importance of Requirements

Some location requirements are more important than others in that a relative shortage of one input may preclude further consideration of some areas. For example, stringent waste-disposal regulations have precluded the location of pulpmills in many areas. And lack of certain timber species or labor skills have prohibited the location of plants in some places. But often it is not readily apparent which requirements weigh most heavily in the location decision.

It was pointed out earlier that the methods of production at a given time are generally taken as being constant, and firms do not generally consider substitution among the factors of production. On the other hand, they do consider *interactions* among the costs of these factors, and this is the crux of economic-location

theory. It is possible to analyze these cost interactions and to determine, in turn, the relative importance of the various factors. This consideration will be referred to as "cost substitution."

For instance, suppose a sawmill that produces 20,000 board feet of lumber per day requires 20,000 board feet of sawlogs per day and 10 laborers working 8 hours per day. Each cost dollar per 1,000 board feet of sawlogs is equivalent to 25 cents per hour in labor costs. Hence, if the sawmill operator decides that he can operate efficiently with a sawlog cost of $60 per 1,000 board feet and a labor wage rate of $1 per hour, he can operate just as efficiently if sawlogs cost $59 per 1,000 board feet and the labor wage rate is $1.25 per hour; the total cost of producing 1,000 board feet of lumber will not change. Therefore the costs can be substituted.

The rate of cost substitution can be expressed as the change in the cost of one factor that is equivalent to an equal but opposite change in the cost of another factor. Such rates can be expressed for simple cost factors for which quantity requirements and average costs have been determined. Only factors that have been considered to be important in the location decision (that is, factors for which costs might vary among locations) are considered here.

The rate of cost substitution is defined as the change in cost that is equivalent to 10-percent changes in the cost of wood, using average costs as a base. For the lumber industry, for example (table 3), a 10-percent change in the cost of wood delivered at the plant is equivalent to a 61-percent change in labor wage rates, or to a 578-percent change in the average cost of electricity. And a 10-percent change in the cost of wood is equivalent to greater percentage changes in the cost of all other factors. This suggests that wood costs are the most important factor governing plant location in the lumber industry. That is, the smaller the percentage change that is equivalent to a 10-percent change in wood costs, the greater is the importance of the factor represented by this change.

To illustrate this point: a 10-percent change in wood costs for the lumber industry represents a change of $5 in the cost of

Table 3.—*Rates of cost substitution among inputs, in percent*[1]

Inputs	Lumber	Particle board	Wood-pulp	Furniture
Wood	10	10	10	10
Labor	61	9	36	5
Transportation	25	14	20	14
Electricity	578	35	44	155
Forest land	333	480	647	—
State and local taxes	222	55	64	40
Industrial site	2,100	2,500	2,400	4,100
Local financial assistance	6,250	750	1,050	620
Particle board	—	—	—	18

[1]Percent change in cost of inputs equivalent to a 10 percent change in the cost of the wood input.

producing 1,000 board feet of lumber, while a 10-percent change in the cost of electricity represents a change of only 9 cents in the cost of producing 1,000 board feet of lumber. Thus wood costs are considerably more important than electricity costs for sawmills, and comparisons made on the basis of cost substitution can be used to rank location factors in order of their importance.

Changes in cost greater than 100 percent are unlikely for most factors, and downward shifts greater than 100 percent are impossible. Thus, while it is quite possible that a 10-percent difference in wood costs can be found among locations, it is much less likely that a difference in labor costs of 61 percent can be found; and it is quite unlikely that a difference in electricity costs of 578 percent can be found among locations that are otherwise comparable.

Average costs for location requirements in the northern Appalachians are shown in table 4. These estimates, which were obtained from respondents interviewed in this study, were used as a base for estimating rates of cost substitution. In addition, they can be used for comparing the suitability of particular locations with the northern Appalachian average.

Rates of cost substitution for all four industries are shown in table 3. The rates are converted by dividing into the rate for the

Table 4.—*Average costs for inputs for average plants in the northern Appalachians*

Location Factors	Lumber	Particle Board	Woodpulp	Furniture
FACTORS WHOSE COSTS VARY WITH LOCATION				
1. Wood:	Sawlogs $50 per 1,000 bd. ft. delivered to the sawmill.	Roundwood $16 per standard cord delivered to the plant.	Pulpwood $16 per standard cord delivered to the mill.	Lumber $120 per 1,000 board feet delivered to the plant.
2. Labor, per hour:	Skilled $2.25, semiskilled 1.75, unskilled 1.25.	Skilled $2.00, semiskilled 1.60, unskilled 1.25.	Skilled $2.70, semiskilled 2.45, unskilled 2.00.	Skilled $1.70, semiskilled 1.35, unskilled 1.20.
3. Forest land:	$7.50 per acre, excluding timber.	$7.50 per acre, excluding timber.	$7.50 per acre, excluding timber.	—
4. Electricity:	$0.023 per kwh.	$0.020 per kwh.	$0.018 per kwh.	$0.020 per kwh.
5. Transportation to major markets:	$20 per 1,000 bd. ft.	$13 per 1,000 sq. ft.	$11 per ton	8% of manufacturing costs (not including transportation costs).
6. Industrial sites:	$400 per acre	$400 per acre	$500 per acre	$400 per acre
7. Investment in plant and equipment:	6%	6%	6%	6%
8. State and local taxes:	2½% of sales dollar.	2½% of sales dollar.	2½% of sales dollar.	2½% of sales dollar.
9. Particle board:	—	—	—	$135 per 1,000 sq. ft.
FACTORS WHOSE COSTS DO NOT VARY WITH LOCATIONS				
1. Resin:	—	$0.08 per lb.	—	—
2. Chemicals, per ton:	—	—	Sulfur $25, soda ash $34, chlorine $75, caustic soda $62.	

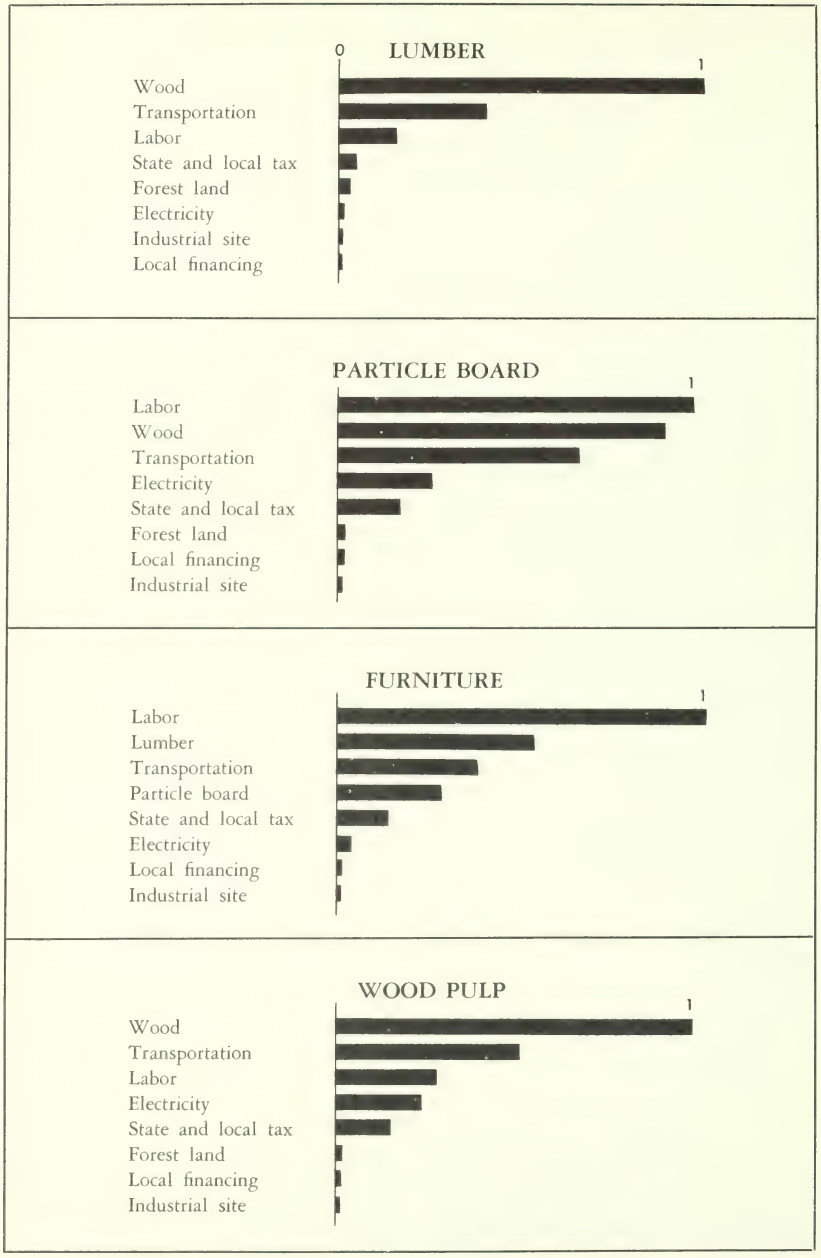

Figure 1.—Importance of selected location factors relative to the most important factor (top bar in each case). The ratios were determined by dividing rate of cost substitution (table 3) of the most important factor by the rate of cost substitution of the selected factor.

most important factor to show the relative importance of each factor. Figure 1 indicates these comparisons for each industry. Some comments regarding these rankings are in order.

First, for all four industries, the most important factors are wood, transportation, and labor. For the three primary wood-using industries, wood is at the top of the list, or very close to the top. For the furniture industry, labor is substantially more important than wood, although wood and particle board taken together are of substantial importance. Thus all four industries are raw-material-oriented (Fuchs 1962, Perloff and others 1960), although this orientation is much less strong in the furniture industry.

Second, differences in labor productivity may have some impact on the location decision. If wage rates are held constant, labor appears to be a more important factor relative to wood where labor productivity is low. However, increased labor productivity is generally associated with increased wage levels, and to a large extent this probably holds the impact of labor nearly constant on the location decision. This, of course, is aside from the question of particular labor skills or other factors, such as degree of unionization, that may affect the evaluations made by the decision-maker.

Third, the low rank of state and local taxes, and particularly industrial site and local financial assistance, suggest that industrial-development agencies are relatively ineffective in providing economic assistance to new wood-using firms through lowering taxes and providing financial assistance. This point is not wholly unexpected. Others have suggested that taxes are of little real importance in the location decision (Survey Research Center 1950). The fact that the financial-assistance plans used in this study provided help only with industrial-site land and buildings suggests that these plans would be of little real help to most wood-using firms, for which land and building requirements are not large. However, these agencies may be more important as promotional organizations and as compilers of basic information (Mueller and others 1961).

Although these rankings have been developed only for certain types and sizes of plants in the four industries, some comments

regarding their application to other wood-using plants are also in order. In general, proportional changes in the location requirements could be expected for any changes in plant size, and the relative importance of the various requirements would retain the same order. Changes in the type of processing within the industries considered would affect primarily raw material specifications. For example, most pulping processes are not as catholic in species preferences as the semichemical process; and lumber produced for specific markets may have specific species and grade requirements. Waste-disposal problems differ somewhat among the various pulping processes.

Of the wood-using industries not specifically covered in this report, the most important in the Appalachian region are the secondary industries other than furniture. It is likely that raw-material costs are the most important factor for these industries. Labor costs and skills are certainly less important for them than for the furniture industry. In this group, industries producing goods for industrial use (pallets and containers) are probably restricted more by transportation costs than those producing goods for use by consumers and in construction (turnings and flooring).

Implications for Action

What meaning does this study have for industrial-development agencies interested in promoting industrial plants in the areas that they represent? These agencies engage in a number of activities: they assemble and disseminate data describing their areas; they contact prospective firms; they advertise; they provide inducements in the form of reduced taxes or lowered interest rates on capital investment; they develop sites and provide buildings.

Development agencies also have a choice of the industries at which they will direct their efforts. The industries that were considered in this study differed in the manner in which they made the location decision and in the order of importance of factors that were considered. Thus, development agencies might

vary their approach depending on the particular industry they hope to attract.

They might also choose industries for their potential effects upon the region or community. Plants in some industries obviously employ more people than plants in other industries. Wage rates are likely to be higher in some industries. Additions to the taxable real estate base and increases in subsidiary industries may also differ. Though this study was not directed at analyzing the impact on the community of new plants in the various industries, it does indicate that there are substantial differences among plants.

And this study does provide a means for development agencies to choose among industries on the basis of availability and cost of location requirements. In addition, our understanding of the location decision for the four industries considered in this report can be used to guide the actions of development agencies in attempting to attract new wood-using industries. Each industry will be considered separately.

Lumber. — Entrepreneurial talent for the average new sawmill generally develops from within the area in which the sawmill will be located. The location decision does not ordinarily involve a choice among possible sites; instead it involves a decision whether to build or not build in a given area. The entrepreneur's decision to build a sawmill depends on his evaluation of the raw material available and of the markets that are available for the projected lumber output.

Development agencies interested in increasing the lumber output in their areas can direct their activities toward developing the interest of latent entrepreneurial talent in the area and of suppliers of local capital. This could be done by providing information and by identifying opportunities in terms of available timber and potential markets.

To be more specific, the nature of the raw-material supply determines in part the type of markets that can be entered. The location of the markets for hardwood lumber is important in determining the profitability of new sawmills. Development agencies could direct their attention at matching timber supplies

with the most profitable market opportunities and at providing this information to interested parties within the area.

Particle board. — Several possible locations are generally considered for new particle-board plants. The most important considerations are the availability of a suitable raw-material supply, low labor costs, and low transportation costs to the available markets. Other economic considerations are of relatively little importance.

Industrial-development agencies could direct their efforts toward assembling information to describe the raw-material supply and labor situation within their area, and information about market outlets and transportation costs to these markets. This information could then be provided to firms that might be interested in building new particle-board plants. Particle-board plants have usually been constructed by firms already in the wood products field — plywood producers, lumber producers, and pulp and paper producers. Firms in these fields would be potential customers for information about particle-board production possibilities.

The identification of areas that contain species suitable for particle-board manufacture — principally the pines and some of the soft-textured and light-colored hardwoods — is particularly important. Woodpulp firms compete keenly for these species in some areas. However, the quantity of wood required for an average particle-board plant is substantially less than that required for an average pulpmill. As a result, pockets in which the raw-material supply is sufficient and in which competition is negligible could be particularly attractive to new particle-board plants.

Information about prevailing labor wage rates could be provided for the standard skill classes in the area. Unemployment levels might also be of interest. Important market information would include both the types of markets available and transportation rates to these markets.

Woodpulp. — The decision to construct new pulping capacity involves the consideration of many potential locations. Generally the decision is made by a firm already in the business of producing pulp and paper. Development agencies interested in

attracting such facilities could take two types of action. First, they could provide information about the important cost factors: wood supply, transportation to markets, and utility costs. Second, they could take direct action to make industrial sites available and to ease waste-disposal requirements.

Both the cost of obtaining wood and the availability of particular species may be important in locating a pulpmill. In the hardwood region, the availability of some softwood either in the area of the potential mill site or accessible through a one-line railroad haul is generally significant. Softwood equivalent to 10 or 20 percent of the mill's total requirements would probably be sufficient. As with particle-board plants, competition from other users for limited supplies of the important species might be a limiting factor — especially considering that the quantities of wood required by a pulpmill are large.

In the long run, sources of softwood pulpwood could be developed through planting programs. However, in the space of a few years, development of a wholly new supply is not feasible. The short-run emphasis of the development agencies might be placed on identifying the location of existing supplies, and determining their availability; and, if there are some existing supplies, promoting softwood planting programs to meet the needs of potential mills when the present supplies are exhausted.

Although the cost of industrial sites is unimportant, suitable sites in the Appalachian region may be hard to find. Development agencies might identify sites that have the necessary physical requirements (water, rail sidings, and power connections in particular); and, if necessary, they might consolidate ownership of such sites so that pulpmill firms could obtain the whole site free from encumbrances.

Obtaining sites where water-supply and waste-disposal requirements can be met is difficult. Water-supply requirements are rigid for a given pulpmill, but there is little problem in judging the suitability of a particular supply. On the other hand, the impact of waste disposal on a particular stream is not easy to specify; in addition, requirements of water authorities are commonly incompletely specified. This leads to uncertainties over what waste-disposal facilities the pulpmill will have to install.

Development agencies might be able to reduce these uncertainties. One approach would be to develop a rigid set of standards that would have to be met by any mill. Allowable levels of pollution and the specific facilities that would be required to meet these levels would have to be carefully defined. This approach might discourage some new plants, but it also might attract others capable of easily meeting the standards.

A second approach would be to develop, in conjunction with the regulating commission, a flexible set of standards that would allow for negotiation between the development agency and the pulp firm. This might reduce uncertainties enough to attract a new plant. In this way, communities might modify pollution controls advantageously. Or perhaps they might provide for staged development of pollution controls in return for a promise of increased employment and payrolls (Ciriacy-Wantrup 1961).

Furniture. — Labor, both in terms of wage rates and skills, is clearly the most important factor determining the location of wooden furniture plants. This is true if the location decision is made internally by persons in the area, which is likely for small plants. It is also true if the decision is made externally, which is likely for medium and large plants.

The skills needed in furniture plants are not reflected in the standard skill classifications used by most labor census bureaus. As a result, industrial-development organizations might find it necessary to conduct special canvasses of labor skills if they are to judge satisfactorily the suitability of the area for furniture plants. Where the quantity of skilled woodworking labor is negligible, efforts could be directed at training people in woodworking skills. In areas that have any shortcomings in labor skills for furniture plants, efforts of the development agency might be better directed at attracting plants to make relatively low-quality furniture rather than plants to make high-quality furniture.

Lumber costs are second to labor costs in importance. Species requirements are usually broad in terms of geographical origin, and appear to change rather frequently. Therefore, the impact on the location decision of the lumber supply in a particular area may be slight.

There seems to be a tendency for furniture plants to concentrate in certain areas. Development agencies should consider this as a factor in determining the suitability of an area and in choosing among potential locations. They could do this either by emphasizing locations close to centers of current furniture production or, more ambitiously, by working toward the development of a concentrated area of furniture production. In the latter case, concentrating labor-training programs in one area and negotiating with several firms for contiguous locations might prove to be successful.

Summary

An improved understanding of the location decision is important to industrial-development agencies attempting to attract new plants to their areas. This study was directed at improving our knowledge of the location decision in four wood-using industries — lumber, particle board, woodpulp, and furniture. The cost of wood, labor, and transportation were found to be the most important factors that affect choice of location in all four industries, but the relative importance of these factors differs among the industries. Some factors — state and local taxes, local financial assistance, and the cost of industrial sites, which in the past have been stressed by development agencies — were found to be of relatively little importance for the wood-using industries. It is suggested that development agencies intent on attracting these industries should concentrate on providing potential firms with information organized in terms of the requirements of each industry.

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Estimating maximum allowable timber yields by Linear Programming

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Estimating maximum allowable timber yields by Linear Programming

About the author . . .

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Introduction

FORESTERS, like many other professional or business men, are very often interested in extreme rather than average situations. For example, they strive for maximum dollar returns, growth, and quality; or, conversely, they strive for minimum costs, mortality, and defect. Sometimes the course of action necessary to achieve a maximum or minimum situation is quite evident. However, under other circumstances the possible courses of action may be so numerous or conflicting that the best choice among them cannot be reasoned out. In such complicated situations, linear programming may serve as a useful analytical tool.

Linear programming is a mathematical technique that provides a maximum or minimum solution to a linear equation when the variables in the equation are restricted within certain limits. Many common situations can be expressed in the form of simple linear equations. For example, the weekly grocery bill can readily be expressed as a linear sum of the quantity of each food item times its unit cost; and here the quantities are the variables and the unit costs are the constants in the equation. Carrying this example one step further, the concept of limitations upon the variables is easily

comprehended: one might restrict the amount of each type of food to a certain weekly quota, or might restrict the amount spent to certain dollar values so as to achieve a reasonably balanced diet.

In forestry, linear programming so far has been used primarily for analyzing economic problems of allocation. The technique has seldom, if ever, been applied to the solution of problems in mensuration, silviculture, or protection, possibly because few foresters are familiar with its use and limitations. However, several common forestry problems appear to be amenable to linear programming. An approach to the solution of one of these problems, the estimation of maximum allowable timber yields, will be described in this paper.

General Equations

Assuming an unbalanced even-aged forest comprised of unequal proportions by area of several age classes, the yield of that forest (from clearcutting, for example, coupled with intermediate thinnings,) over the first operating cycle[1] equals the sum of the area cut in each age class times the harvestable volume per acre plus the area thinned in each age class times the volume thinned per acre. Similarly, the total yield of the forest over a rotation equals the sum of the yields in all operating cycles within the rotation. Thus, total yield over a rotation can be expressed as the following linear equation:

$$[1] \qquad Y = \Sigma\Sigma A_{ij}\ V_{ij} + \Sigma\Sigma B_{ij}\ T_{ij}$$

in which—

Y = Total yield.
A = Area harvested (acres).
V = Volume per acre harvested.
B = Area thinned (acres).
T = Volume per acre thinned.
i = The number of the operating cycle (first, second, third, etc.)
j = The age class.

[1] In this paper *operating cycle* is defined as the number of years required to examine all portions of the forest and make harvest cuttings or thinnings as necessary.

Now there are many different ways in which an unbalanced even-aged forest can be cut. Some foresters might prefer to make harvest cuttings in only one or two of the older age classes, and to make thinnings in the remaining age classes. Other foresters might prefer to do some harvest cutting in the younger age classes so as to work toward a better age-class distribution. But despite divergent opinions, most foresters would agree that one main objective of regulation is to maximize the yield of the forest—whether measured in dollars or in volumes. Thus a reasonable objective for a linear programming analysis is to maximize yields as expressed by the above yield equation. In linear programming terminology, this yield equation is called the objective equation or objective function.

But maximum yields are not the only objective of regulation. We might also wish to make sure that approximately equal volumes are harvested during each operating cycle. To introduce this restriction into the linear programming solution, it would be necessary first to express it in an equation of the form:

$$[2] \qquad \Sigma A_{1j}\ V_{1j} = \Sigma A_{2j}\ V_{2j}$$

in which the variables and subscripts are as previously defined. This equation states that the volume cut during the first operating cycle will equal the volume cut during the second cycle. Similar equations can be used to equate the harvests among other pairs of operating cycles.

Another useful restriction on the problem might be that equal areas are harvested in each operating cycle so as to bring about a balanced age distribution by the end of the first rotation. This restriction would be expressed by an equation of the form:

$$[3] \qquad \Sigma A_{1j} = \Sigma A_{2j}$$

which states that the area harvested during the first operating cycle equals the area harvested during the second cycle. For this restriction to be effective, it would also be necessary to specify that no subsequent harvest cutting will take place in the newly created age classes during the remainder of the rotation.

Another very necessary restriction on the problem is that areas harvested and thinned in any age class will be equal to or less than

the available area. For example, if we began with 100 acres in the 40-year age class, it would be necessary to specify that the area harvested in this age class during the first operating cycle will be no more than 100 acres, and that the area harvested in the 50-year age class during the second cycle (assuming a 10-year cycle) will be no more than 100 minus the area cut during the first cycle. These two relationships can be expressed, respectively, by the equations:

$$[4] \qquad A_{14} \leq 100$$

$$[5] \qquad A_{25} \leq 100 - A_{14}$$

In actual practice, the problem will probably be much more complicated than the general one considered above. An unbalanced even-aged forest might be divided into sites, types, and stocking classes as well as age classes. In such cases, the objective equation and the restrictions would be considerably more involved. Furthermore, many additional restrictions could be written into the problem, depending on the particular management situation and objectives. However, the equations and examples presented so far provide a fairly representative picture of how the problem of yield estimation can be approached through linear programming.

Solving the equations that comprise a linear programming problem is an iterative and often lengthy process that requires some facility with simultaneous equations. A simple description of linear programming theory may be found in Kemeny, Snell, and Thompson,[2] and a more advanced discussion of the theory and computations in Boulding and Spivey.[3] The details will not be covered here. For many practical problems, an electronic computer is necessary; and fortunately the necessary computer programs are available.

Three types of solution are possible: (1) an optimum solution giving the values of the variables that will maximize (or minimize) the objective equation; (2) an infinite solution, which occurs when the restrictions on the problem do not set an upper

[2] Kemeny, John G., J. Laurie Snell, and Gerald L. Thompson. INTRODUCTION TO FINITE MATHEMATICS. 372 pp., illus. Prentice-Hall, Inc., Englewood Cliffs, N.J., 1956.

[3] Boulding, Kenneth E., and W. Allen Spivey. LINEAR PROGRAMMING AND THE THEORY OF THE FIRM. 227 pp., illus. Macmillan Co., New York, 1960.

(or lower) limit to the value of the objective equation; and (3) no solution, which results when the restrictions on the problem are not consistent with one another. It is very likely that examples of no solution—as well as optimum solution—will occur when linear programming is used in the estimation of maximum allowable yields. In such cases, it will be necessary to examine the restrictions for consistency, to revise them as necessary, and then to try again.

Two Hypothetical Examples

Linear programming has not yet been applied to a practical problem of yield estimation. No doubt difficulties will be encountered that are not yet evident. However, the solution of two simple hypothetical examples can be given to further illustrate the possibilities of linear programming.

Assume that an unbalanced even-aged forest has three 10-year age classes represented by unequal areas:

Age class, years		
0-10	*10-20*	*20-30*
(acres)	*(acres)*	*(acres)*
60	30	10

And assume further that the rotation age is 30 years, and that we wish to maximize cubic-foot yields over three 10-year operating cycles subject to the restrictions of: (1) equal areas cut per operating cycle; (2) a balanced age-class distribution by the end of the rotation (equal areas in each age class); and (3) areas cut by age classes not to exceed the available acreages. To keep the problem simple, we will eliminate thinning yields from consideration. Hypothetical harvest yields per acre, as might be estimated from a standard or empirical yield table, are given in table 1. In a practical problem, the construction of this yield table so as to reflect present and expected net harvestable volumes per acre would be a very critical step in the yield analysis.

The objective equation for this problem is derived from equa-

tion (1); thinning yields are omitted, and hypothetical harvest yields from table 1 are inserted as constants. We begin with the equation:

$$\begin{aligned}\text{Yield} = {} & A_{11}\,(800) + A_{12}\,(1600) + A_{13}\,(3000) \\ & + A_{21}\,(1100) + A_{22}\,(2000) + A_{23}\,(3200) \\ & + A_{31}\,(1200) + A_{32}\,(2200) + A_{33}\,(3600)\end{aligned}$$

To ensure that the forest will develop toward a balanced age distribution, it is necessary to eliminate all cutting in new stands established during the three operating cycles. This is accomplished

Table 1.—*Hypothetical harvest yields, in cubic feet per acre, by age class and operating cycle*[1]

Operating cycle	Age class, years		
	0-10	10-20	20-30
1	800	1,600	3,000
2	1,100	2,000	3,200
3	1,200	2,200	3,600

[1] These cubic-foot yields were chosen for convenience and are not intended to be realistic. The increase in yields by age class from one operating cycle to another is meant to represent improvement of the stand in net volume resulting from cultural work.

Table 2.—*Area available for cutting and area cut, by age class and operating cycle*

(Primary restriction: development of a balanced age distribution)

Operating cycle	Age class, years						Total cut	
	0-10		10-20		20-30			
	Available	Cut	Available	Cut	Available	Cut	Area	Volume
	Acres	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Cu. ft.*
1	60.00	23.33	30.00	0.00	10.00	10.00	33.33	48,664
2	33.33	.00	36.67	3.33	30.00	30.00	33.33	102,660
3	33.33	.00	33.33	.00	33.34	33.34	33.34	120,024
Total	—	—	—	—	—	—	100.00	271,348

by eliminating appropriate terms from the above equation; namely, the terms involving A_{21}, A_{31}, and A_{32}. Furthermore, if we impose the condition that all of the area in the third age class will be harvested during each operating cycle, three more variables can be eliminated from the objective equation because they can be expressed as:

$$A_{13} = 10$$
$$A_{23} = 30 - A_{12}$$
$$A_{33} = 60 - A_{11} - A_{22}$$

By eliminating terms and variables as explained above and simplifying, the final objective equation is:

$$\text{Yield} = A_{11}\ (-2800) + A_{12}\ (-1600) + A_{22}\ (-1600) + 30{,}000 + 96{,}000 + 216{,}000$$

The restriction of equal areas cut per cycle is expressed by two equations in the form of equation 3. The areal restrictions on the three variables in the objective equation follow the form of equations 4 and 5.

The linear programming solution yielded the area values given in table 2. These values represent the areas to be cut by age class and operating cycle so as to provide maximum yields over a rotation under the specified restrictions of the problem. Equal areas are to be cut during each operating cycle and a balanced age-class distribution will be attained by the end of the rotation as specified in the restrictions of the problem. However, the volume yields will vary considerably from one operating cycle to another.

We may rephrase the restrictions of the problem so as to ensure equal volume yields per operating cycle with no limitations upon areas cut except those imposed by the initial available acreages in each age class.

Once again, the objective equation is derived from equation 1. This time, no complete terms are omitted, but three variables can be eliminated as before and some simplification can be done to provide the following yield equation:

$$Y = A_{11}\ (-2800) + A_{12}\ (-1600) + A_{21}\ (1100) + A_{22}\ (-1600) + A_{31}\ (1200) + A_{32}\ (2200) + 30{,}000 + 96{,}000 + 216{,}000$$

Table 3.—*Area available for cutting and area cut, by age class and operating cycle*

(Primary restriction: equal volumes cut per operating cycle)

Operating cycle	Age class, years						Total cut	
	0-10		10-20		20-30			
	Available	Cut	Available	Cut	Available	Cut	Area	Volume
	Acres	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Cu. ft.*
1	60.00	60.00	30.00	25.67	10.00	10.00	95.67	119,072
2	95.67	95.61	.00	.00	4.33	4.33	99.94	119,027
3	99.94	99.12	.06	.06	.00	.00	99.18	119,076
Total	—	—	—	—	—	—	294.79	357,175

The restriction of equal volume yields per operating cycle is expressed by two equations in the form of equation 2 while the areal restrictions are again represented by equations such as 4 and 5.

The solution to this problem is given in table 3. By cutting the indicated areas, maximum yields can be obtained within the restrictions of the problem. Not only are the volume yields to be equal—except for rounding errors—for all operating cycles, but total volume yields will be much greater than in the first problem. However, a balanced age-class distribution will be sacrificed for higher and more uniform yields. Clearly, it will be desirable to set or attempt to set restrictions upon both volume yields and age-class distribution when applying linear programming to a practical problem of regulation.

Discussion

These two hypothetical problems are for illustration only, and they do not provide results that apply to any actual situation. The primary conclusion to be drawn from comparing the solutions to these problems is that the restrictions set upon a linear programming analysis of allowable yields must be carefully planned and specified to help ensure a realistic and practical solution.

Despite the lack of practical experience and examples, linear programming does appear to offer considerable promise for analyzing the yields of unbalanced, even-aged forests. Linear programming should help to provide estimates of (1) maximum yields under specific conditions, (2) areas to be cut or thinned by age classes, operating cycles, and other categories so as to achieve maximum yield, and (3) the effects of different restrictions or cutting policies upon estimated allowable cut. The use of linear programming for these purposes deserves intensive study.

■

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Estimating
NUMBERS OF CAMPERS
on Unsupervised Campgrounds

by J. Alan Wagar

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NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
RALPH W. MARQUIS, DIRECTOR

A typical family camping scene on Waterville campground, one of the areas included in a study of campsite use in the White Mountain National Forest.

The Author —

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Estimating NUMBERS OF CAMPERS on Unsupervised Campgrounds

How Many Campers?

ANY agency that provides camping facilities needs an accurate record of campers as an aid to efficient planning and administration. However, complete counts of campers are expensive, especially at small unsupervised campgrounds. And although many of the methods now being used for estimating campers are of doubtful accuracy, sampling methods may offer a reliable solution. Sampling procedures that incorporate regression or ratio techniques look especially promising. When these techniques are used, area-wide fluctuations in campground attendance do not necessarily increase sampling error.

Within a large sampling area—for example, in a National Forest—the numbers of campers on many campgrounds may rise and fall in uniform response to such diverse factors as weather, day of the week, vacation periods, insect activity, and fishing seasons. Where this common pattern exists, the number of campers on a sample group of campgrounds may be related to campers on all campgrounds by regression and ratio techniques.

To test these techniques, a study was made on the White Mountain National Forest in New Hampshire from July 10 to September 10, 1961. Campers were counted each evening, according to

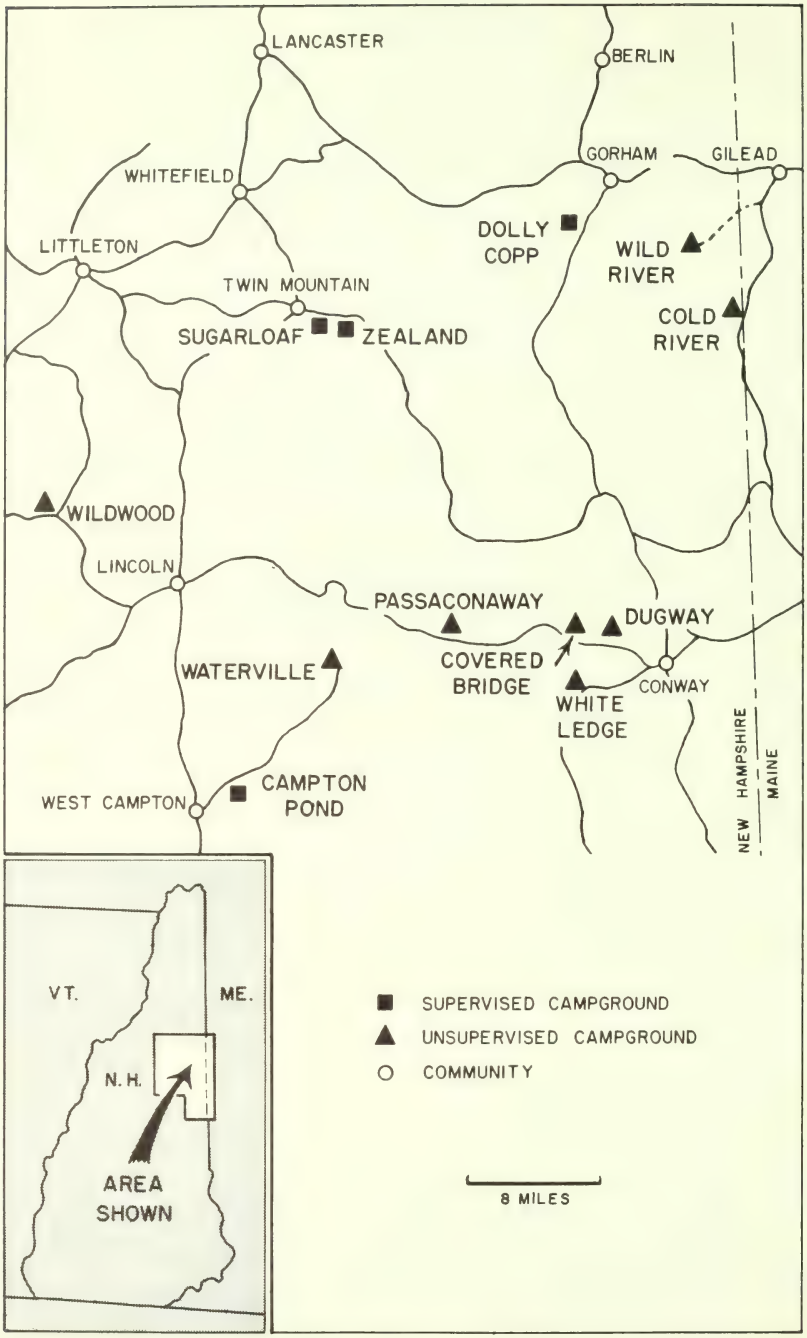


Figure 1.—Locations of campgrounds included in this study, on the White Mountain National Forest, New Hampshire.

a random schedule, on one or more of eight unsupervised campgrounds (fig. 1) grouped into sampling units as follows:

Sampling Unit A.—Wild River and Cold River Campgrounds —21 campsites.

Sampling Unit B.—White Ledge Campground—39 campsites.

Sampling Unit C.—Wildwood and Waterville Campgrounds—48 campsites.

Sampling Unit D.—Dugway, Covered Bridge, and Passaconaway Campgrounds—60 campsites.

These unsupervised campgrounds included a wide range of conditions. At one extreme, Wild River Campground had 7 campsites, was accessible only by an unsurfaced and unmaintained road, and was 10 miles from the nearest village—a community of 50. By contrast, White Ledge Campground had 39 campsites, was adjacent to a paved main route, and was only 5 miles from the nearest town—a community of 1,200. Such dissimilarity tends to make sampling difficult.

From early summer until September 4, as standard administrative procedure, campers were already being registered on four supervised campgrounds—Dolly Copp, Campton Pond, Sugarloaf, and Zealand.

Relating Use of Unsupervised Campgrounds to Supervised Campgrounds

Where attendance at supervised campgrounds is already being recorded, attendance at unsupervised campgrounds can be estimated with few additional counts if unsupervised camping follows the same patterns as supervised camping. To provide data for relating unsupervised use to supervised use, campers were counted simultaneously on all 8 unsupervised campgrounds on 18 randomly selected evenings during the last hour before darkness, from July 10 to September 4. Sixteen of these counts coincided with records of supervised camping. Total counts of unsupervised camping, and the corresponding records of supervised camping,

(table 1) were used to compute the following regression (fig. 2):

$$Y = 51.432 + .309\ X \qquad S_{y.x} = 52.42$$

where:

X = the attendance at supervised campgrounds for one night.
Y = the estimate of unsupervised campers for the same night.
$S_{y.x}$ = the standard error of the estimate.

The regression estimate of unsupervised camping for the 57 nights between July 10 and September 4 is:

$$\begin{aligned} \Sigma Y &= \Sigma(51.432 + .309\ X) \\ &= 57\ (51.432) + .309\ (\Sigma X) \end{aligned}$$

From table 1, $\Sigma X = 77{,}848$, and the estimate for the period is computed as 26,986 camper nights for the 8 unsupervised campgrounds.

The original plan was to determine a variance for each night's estimate of campers. Confidence intervals for the entire period were then to be computed from the sum of these nightly variances. However, this procedure was abandoned because nightly variances are not independent and therefore, according to statistical theory, are not additive. C. Allen Bickford (personal communication) demonstrated that $\sigma^2_{\Sigma Y} = N^2\sigma^2_{\bar{Y}}$ and recommended that variance for the entire season be computed by the formula:

$$S^2_{\Sigma Y} = N(N - n)\ S^2_{y.x} \left\{ \frac{1}{n} + \frac{(\overline{X}_N - \overline{X}_n)^2}{\Sigma x^2} \right\}$$

where:

N = the number of nights in the entire period (57 in this case).
n = the number of nights on which total counts were made (16 in this case).
Σx^2 = the sum of the squared deviations from the mean for the data collected on the n total-count nights.

This is the formula (7.13) for $S^2_{\bar{Y}}$ given by Cochran,[1] multiplied by N^2 and the finite population correction $(1 - n/N)$. Con-

[1] Cochran, William G. SAMPLING TECHNIQUES. John Wiley & Sons, Inc., New York, 320 pp., 1953.

fidence intervals based on the variance given by this formula are:

$$\text{Regression estimate} \pm t \sqrt{\text{variance}}$$

$= 26{,}986 \pm 1{,}374$ camper nights at 95 percent confidence (error of 5.1 percent).

$= 26{,}986 \pm 1{,}907$ camper nights at 99 percent confidence (error of 7.1 percent).

For the data plotted in figure 2, ratio estimation appears as reasonable a procedure as regression estimation. Following Cochran (1953), $R = y/x$ where y and x are sums of sample data—in this case sums of unsupervised and supervised campers, respectively, for the 16 total-count nights (table 1). Thus, $R = 7{,}796/22{,}574 = 0.34535$. The ratio estimate of unsupervised campers for July 10 to September 4 equals R times the total number of supervised campers for the period:

$$= 0.34535\ (77{,}848) = 26{,}885 \text{ camper nights.}$$

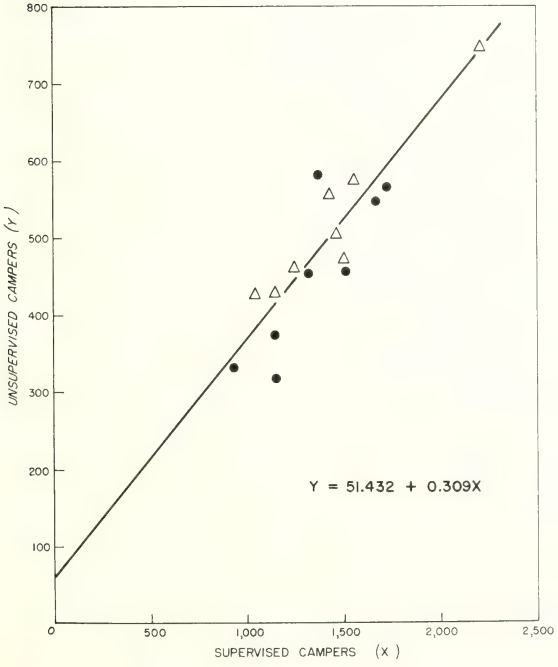


Figure 2.—Regression line for estimating unsupervised campers from camper registration on supervised campgrounds. Triangles represent data collected on weekend nights; round dots indicate data collected on week nights.

Table 1.—Summary of use-count data for campgrounds on the White Mountain National Forest, July 10 to September 10, 1961, in number of campers

(Underlined figures are values for nights when all units were counted)

Date	Unsupervised campgrounds, by sampling units—					Supervised campgrounds
	A	B	C	D	Total	
July						
10	..	..	..	179	..	984
11	17	..	..	..	..	1,102
12	..	..	84	..	..	1,114
13	31	124	80	97	332	930
14	..	120	..	..	..	872
15	6	135	120	166	427	1,056
16	..	..	62	..	..	985
17	28	153	48	144	373	1,151
18	..	178	..	..	..	1,263
19	..	..	70	..	..	1,199
20	..	183	..	..	..	1,296
21	33	..	..	..	..	1,293
22	..	..	..	263	..	1,544
23	31	136	91	215	473	1,506
24	24	..	..	..	..	1,479
25	..	..	..	228	..	1,493
26	..	171	..	..	..	1,553
27	39	152	55	211	457	1,515
28	..	..	77	..	..	1,453
29	47	144	118	264	573	1,569
30	28	..	..	..	..	1,448
31	..	..	..	207	..	1,546
August						
1	41	158	138	212	549	1,666
2	..	..	133	..	..	1,677
3	..	138	..	..	..	1,486
4	48	..	..	..	..	1,494
5	..	..	..	291	..	1,520
6	42	158	112	247	559	1,434
7	..	..	..	264	..	1,585
8	29	..	..	..	..	1,602
9	66	153	127	217	563	1,729
10	..	..	182	..	..	1,634
11	..	173	..	..	..	1,558
12	..	..	..	294	..	1,636
13	38	126	124	219	507	1,469
14	66	157	127	232	582	1,372
15	..	154	..	..	..	1,345

CONTINUED

Table 1.—(continued).

Date	Unsupervised campgrounds, by sampling units—					Supervised campgrounds
	A	B	C	D	Total	
16	..	..	..	247	..	1,388
17	..	..	112	..	..	1,236
18	..	..	137	..	..	1,348
19	55	..	..	..	..	1,353
20	38	116	64	208	426	1,167
21	..	62	..	..	..	1,162
22	..	..	..	237	..	1,206
23	28	..	..	..	..	1,262
24	..	..	67	..	..	1,307
25	28	77	122	227	454	1,312
26	22	88	120	230	460	1,283
27	17	..	..	..	..	1,206
28	..	..	79	..	..	1,191
29	27	49	73	166	315	1,191
30	..	66	..	..	..	1,254
31	37	..	..	..	..	1,137
September						
1	..	125	..	..	..	1,879
2	65	194	182	305	746	2,224
3	..	..	..	283	..	1,846
4	..	49	..	..	..	338
5	..	..	17	..	..	..
6	6	25	19	33	83	..
7	7	..	..	..	..	..
8	..	..	..	54	..	..
9	..	..	17	..	..	..
10	7	14	7	19	47	..

Sums and averages	Unsupervised campgrounds, by sampling units—						Supervised campgrounds
	A	B	C	D	Total		
All nights	..	..	..	..	..	..	77,848 (57)[1]
Total count	628	2,159	1,727	3,412	7,926	7,796	22,574
nights	(18)	(18)	(18)	(18)	(18)	(16)	(16)
Other	323	1,419	1,037	2,547	..	..	..
nights	(11)	(11)	(12)	(11)	..	..	..
Aver.	32.793	123.379	92.133	205.483	..	..	..
per night	(29)	(29)	(30)	(29)	..	..	..

[1] Numbers in parentheses represent the number of nights of data included in the various sums and averages.

Variance is estimated as:

$$\frac{N(N - n)}{n} \cdot \frac{\sum_{i=1}^{n}(y_i - Rx_i)^2}{(n - 1)} = 391{,}233.27$$

where:

N = number of nights in the entire period (57).
n = number of total-count nights in the period (16).
y_i = number of unsupervised campers on night i.
x_i = number of supervised campers on night i.

Confidence intervals based on the variance given by this formula are:

Ratio estimate $\pm$ t $\sqrt{\text{variance}}$

= 26,885 $\pm$ 1,333 camper nights at 95 percent confidence (error of 4.9 percent).

= 26,885 $\pm$ 1,843 camper nights at 99 percent confidence (error of 6.9 percent).

Thus, where they are applicable, ratio methods give estimates and confidence intervals comparable to those obtained from regression.

Estimating Number of Campers from a Sample

Where there is no registration of campers, camper numbers may be estimated from counts on a sample of campgrounds. To test the effectiveness of various samples, the 18 total counts of unsupervised camping (the underlined figures in table 1) were used to develop 4 regressions. These relate use on each sampling unit to total use on all unsupervised campgrounds and are as follows:

$Y_A = 181.634 + 7.415\ X_A$	$S_{y.x} = 102.47$
$Y_B = 83.331 + 2.976\ X_B$	$S_{y.x} = 86.24$
$Y_C = 113.374 + 3.408\ X_C$	$S_{y.x} = 77.91$
$Y_D = 30.571 + 2.162\ X_D$	$S_{y.x} = 52.94$

where:

X_A, X_B, X_C, and X_D = one-night counts of campers on Sampling Units A, B, C, and D respectively.

Y_A, Y_B, Y_C, and Y_D = estimates of total use for one night.

These equations and the data on which they are based are graphed in figures 3, 4, 5, and 6. Because of the large Y-intercepts in some of these graphs, ratio methods were not considered appropriate for estimates based on these sampling units.

On each night not devoted to a total count, use was counted on whichever sampling unit was indicated by a randomly determined schedule. These counts are the numbers not underlined in table 1. By using each of these counts in the appropriate regression, total use could be estimated for any night on which one of the sampling units had been counted.

The relationship $\Sigma Y = N.a + b\ (\Sigma X)$ is again applicable, but N now equals the number of nights, excluding total-count nights, on which a given sampling unit was counted. Using the sums of campers for all nights when total counts were not made (table 1), the use estimate for all but total-count nights would be

$$\begin{aligned} Y_A &= 11(181.634) + 7.415(\ 323) = 4393.019 \\ Y_B &= 11(83.331) + 2.976(1419) = 5139.585 \\ Y_C &= 12(113.374) + 3.408(1037) = 4894.584 \\ Y_D &= 11(30.571) + 2.162(2547) = 5842.895 \\ &\text{Total camper nights} = \overline{20{,}270} \end{aligned}$$

When use for the 18 total-count nights is added, the estimate of unsupervised camping for the period July 10 to September 10 is: 20,270 + 7,926 = 28,196 camper nights. This is an unbiased estimate of total use. However, confidence intervals must be rather awkwardly handled because the variances from regressions Y_A, Y_B, Y_C, and Y_D are not independent and cannot be added as was planned originally.

During analysis of data from this study, it became obvious that the same sampling unit should have been counted every night, and that using a different sampling unit each night was not good procedure. Because four sampling units were used, only approximate confidence limits can be placed on the total estimate of campers for the season. These limits are an approximation of

the confidence limits that would have resulted if each sampling unit had been the one on which nightly counts were made. This indicates the precision that might be expected for estimates based on sampling units of various sizes. The formula

$$S^2_{\Sigma Y} = N(N - n)S^2_{y.x}\left\{\frac{1}{n} + \frac{(\overline{X}_N - \overline{X}_n)^2}{\Sigma x^2}\right\}$$

would again be applicable if $\overline{X}_N$ were known. But campers were counted on each sampling unit only 29 or 30 times rather than on all N nights during the sampling period ($N = 63$ in this case). However, an assumption that is approximately correct allows confidence limits to be computed for each sampling unit as if it had been counted all 63 nights.

It has been assumed that the means of the 29 or 30 counts made on each sampling unit are equal to the means that would have been obtained if use had been counted on the same unit all 63 nights. In the formula given above, the term

$$\frac{(\overline{X}_N - \overline{X}_n)^2}{\Sigma x^2}$$

contributes a very minor part to the value of $S^2_{\Sigma Y}$ and inaccuracies from using the wrong value of $\overline{X}_N$ can be expected to be very small. By using an estimate of $\overline{X}_N$ (table 1) we can identify the approximate error that would have occurred if all sampling had been on one unit.

Using the above formula, if campers had been counted on all 63 nights of the season on a single sampling unit, approximate confidence limits would be as follows:

Sampling unit	*Campsites in unit*	*Estimate of camper nights*	*Confidence level*	*Error, percent*
A	21	28,196 ± 2,730	0.95	9.6
		28,196 ± 3,750	.99	13.2
B	39	28,196 ± 2,287	.95	8.1
		28,196 ± 3,142	.99	11.1
C	48	28,196 ± 2,070	.95	7.3
		28,196 ± 2,843	.99	10.1
D	60	28,196 ± 1,434	.95	5.1
		28,196 ± 1,970	.99	7.0

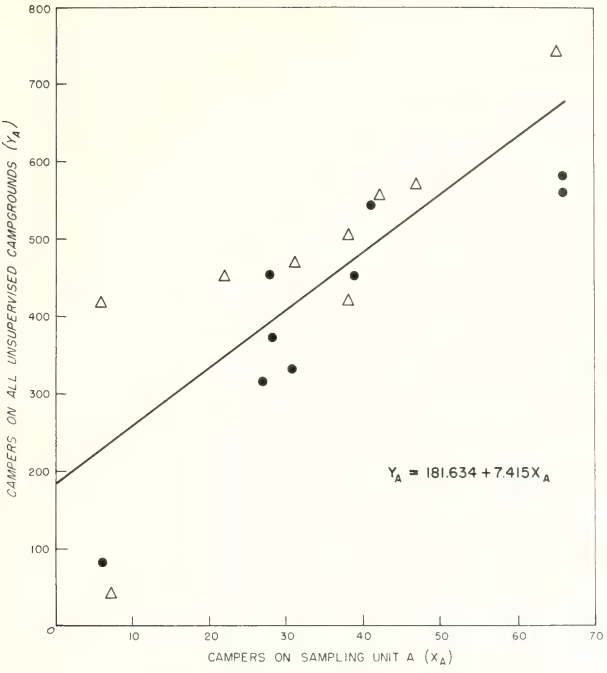


Figure 3.—Regression line for estimating total unsupervised camping from a count of campers on Wild River and Cold River Campgrounds (Sampling Unit A). Triangles represent data collected on weekend nights; round dots indicate data collected on week nights.

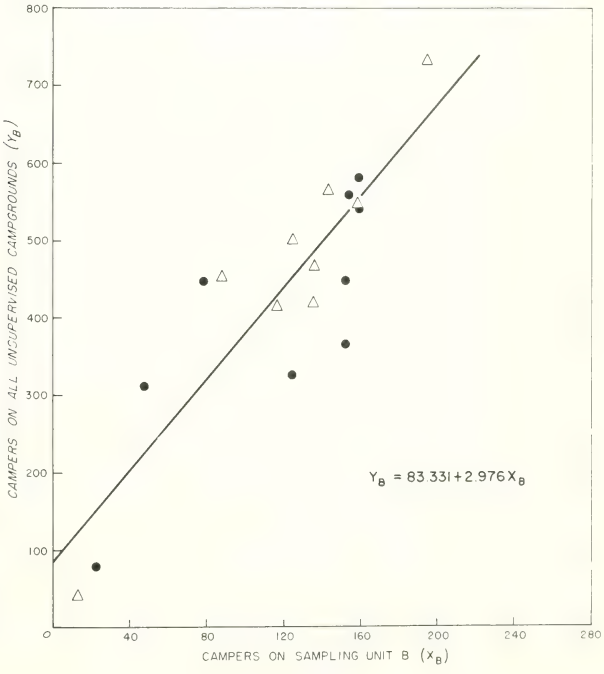
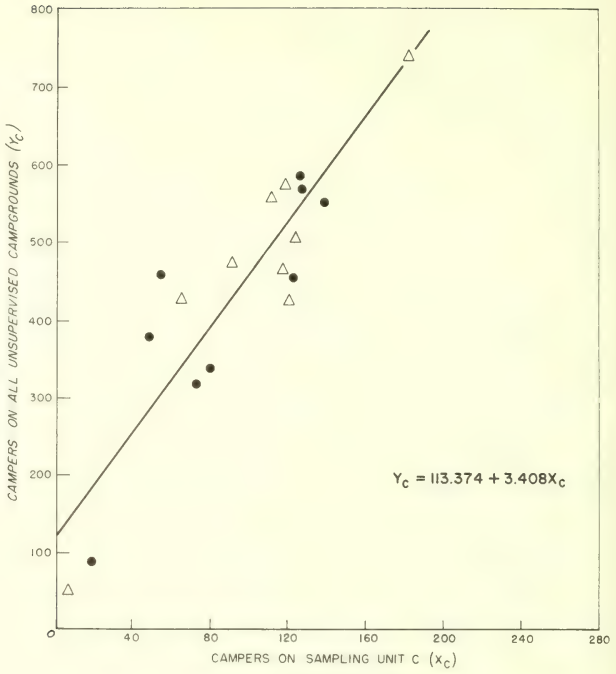


Figure 4.—Regression line for estimating total unsupervised camping from a count of campers on White Ledge Campground (Sampling Unit B). Triangles represent data collected on weekend nights; round dots represent data collected on week nights.

Figure 5. — Regression line for estimating total unsupervised camping from a count of campers on Wildwood and Waterville Campgrounds (Sampling Unit C). Triangles represent data collected on weekend nights; round dots indicate data collected on week nights.



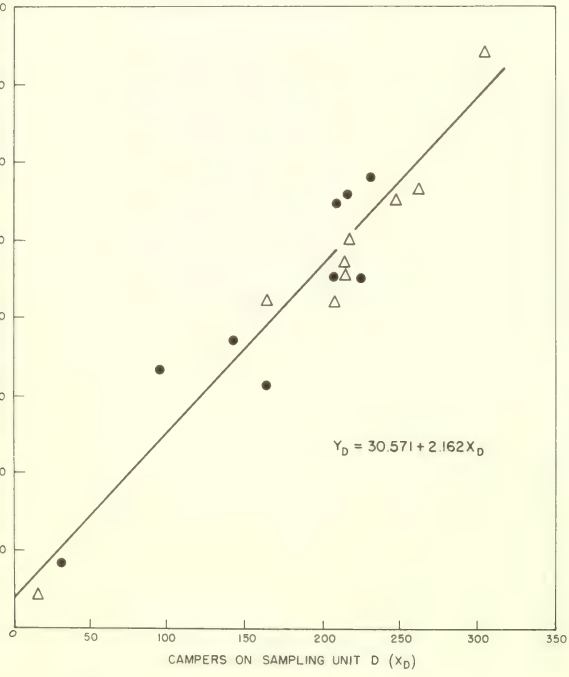


Figure 6. — Regression line for estimating total unsupervised camping from a count of campers on Dugway, Covered Bridge, and Passaconaway Campgrounds (Sampling Unit D). Triangles represent data collected on weekend nights; rounded dots indicate data collected on week nights.

Note that error decreases as sample size increases. This provides a basis for estimating the sample size necessary for a chosen level of precision.

Application of Results

Sampling is only one method of estimating numbers of recreationists, and consideration of other methods should not be overlooked just because they were not evaluated in this study. For example, in many situations improved methods of using vehicle counters might give better results at less cost. However, where vehicle counts are not meaningful, sampling offers an effective method of estimating recreational use.

It is fortunate that sampling precision depends primarily upon sample size rather than upon the size of the total population. Thus, if applied where there are many campsites, the regression or ratio estimation procedures described here should give acceptable precision with sampling rates that are economically feasible. For the data of this study, regression and ratio estimation proved much more efficient than random sampling. But there were only 168 campsites in the total population and only 63 nights in the sampling period. This meant that a rather high rate of sampling was required for collecting enough data to establish relationships. With longer camping seasons and greater numbers of campsites, the same levels of precision could be achieved with lower sampling rates. And where regressions (or ratios) prove to be usable for several years, sampling rates could average still lower.

Where it is possible to estimate numbers of campers on unsupervised campgrounds from actual registration on supervised campgrounds, this procedure may offer the most precise estimate for the least additional cost. For example, (1) if total counts on 18 nights were adequate for relating unsupervised use to records of supervised use, (2) if the relationship proved usable for 3 years, and (3) if each season lasted 100 days, then the required rate of sampling would average only 6 percent per year. At a confidence level of 95 percent, and for conditions as they existed

Campers at Dugway campground. Use of unsupervised campgrounds such as this one was compared with use of supervised campgrounds, where all campers were registered.

in this study, this rate of sampling would provide an estimate within approximately 5 percent of actual use.

However, it must be recognized that relationships between supervised and unsupervised camping will provide useful estimates only when camper numbers fluctuate in approximately the same patterns on both types of areas.

Where campers are not registered at all, it will be necessary to select a sample of campgrounds where nightly use is highly correlated with total nightly use on all campgrounds in the sampling area. Rather than count a different sample each night, as was done in this study, use should be counted every night on the same sample of campsites.

As an example of what sampling rates and precision might be expected, assume (1) that campground conditions will be as they existed in this study, (2) that a total of 500 campsites will be within the area being sampled, (3) that 18 total counts will establish an estimation equation that can be used for 3 years, and (4) that a sample of 24 campsites will be counted every night. Under these conditions the total rate of sampling (18 total counts plus nightly counts on the sample) would average approximately 10 percent per year. At a confidence level of 95 percent, this would provide an estimate within approximately 10 percent of actual use.

Procedures already in use at some areas might contribute to economy in sampling. Some campgrounds now have self-registration boards with a numbered peg for each campsite. Camping parties are required to fill out a card and hang it on the peg corresponding to the campsite they wish to occupy. At a few campgrounds (U.S. Forest Service 1961)[2] tickets must be purchased daily from a vending machine and displayed in the window of a locked box by the campsite. Where such procedures are in use, the proportion of people who fail to register or to buy tickets may be quite stable. If that is the case, total use probably can be estimated by regression or ratio methods from records of self registration or ticket sales. This would greatly reduce the costs of data collection and would allow higher rates of sampling.

Once use estimates and confidence limits are determined for individual sampling areas, they can be combined to give more precise estimates for broader regions. Thus, where the use estimate for sampling area i is represented by the expression:

$$\text{Estimate}_i \pm \text{Interval}_i$$

the combined estimate of use on N areas will be:

$$\sum_{i=1}^{N} \text{Estimate}_i \pm \sqrt{\sum_{i=1}^{N} (\text{Interval}_i)^2}$$

[2] United States Forest Service. CHARGING FOR USE OF NATIONAL FOREST RECREATION AREAS: AN ADMINISTRATIVE STUDY. U.S. Forest Serv. California Region, 13 pp., 1961.

For example, if seasonal use estimates on four hypothetical areas are:

Area	Estimate of camper nights	Error, percent
1	30,000 ± 3,000	10
2	40,000 ± 3,200	8
3	20,000 ± 2,400	12
4	50,000 ± 5,500	11

Then total use would be:

$$140{,}000 \pm \sqrt{(3{,}000)^2 + (3{,}200)^2 + (2{,}400)^2 + (5{,}500)^2}$$

$$= 140{,}000 \pm 7{,}434 \text{ camper nights } (5.31\text{-percent error}).$$

Thus the sampling methods described here would be efficient if applied on a large enough scale. This would require (1) a large number of campsites on one sampling area or (2) the combining of independent estimates from several sampling areas.

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Evaluating and Scheduling WHITE-PINE WEEVIL CONTROL in the Northeast

by Robert Marty and D. Gordon Mott

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Evaluating and Scheduling White-Pine Weevil Control in the Northeast

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A FORMIDABLE LOSS

ALTHOUGH it is not eye-catching to the casual observer, damage done by the white-pine weevil is widespread and serious on white pine trees in the Northeast. Weevil injury may be costing Northeastern woodland owners and lumber producers as much as 7 million dollars each year, due for the most part to the lumber degrade that weevil injury causes.

The direct economic losses are indeed formidable. Yet the indirect influence of this forest pest is perhaps of even greater consequence. Uncontrolled weeviling limits the usefulness of timber-management activities, often to such an extent that no cultural practices can be undertaken profitably. Uncontrolled weeviling reduces the quality of some pine stands so much that they drop below the commercially operable margin, stripping owners of not only a part, but of all income from these stands. Finally, uncontrolled weeviling has resulted in a region-wide pine resource of such increasingly poor quality that it cannot support profitable processing enterprises.

Weevil injury is not the only problem faced by pine growers and processors. But is it the most pressing one for many, and it is a problem that can be solved. Weevil injury can be controlled—effectively and profitably—in many stands.

The purpose of this report, addressed to all those interested in pine management and pest control, is to develop an economic evaluation procedure that can help in deciding *where* to practice weevil control, and to provide information about weevil injury

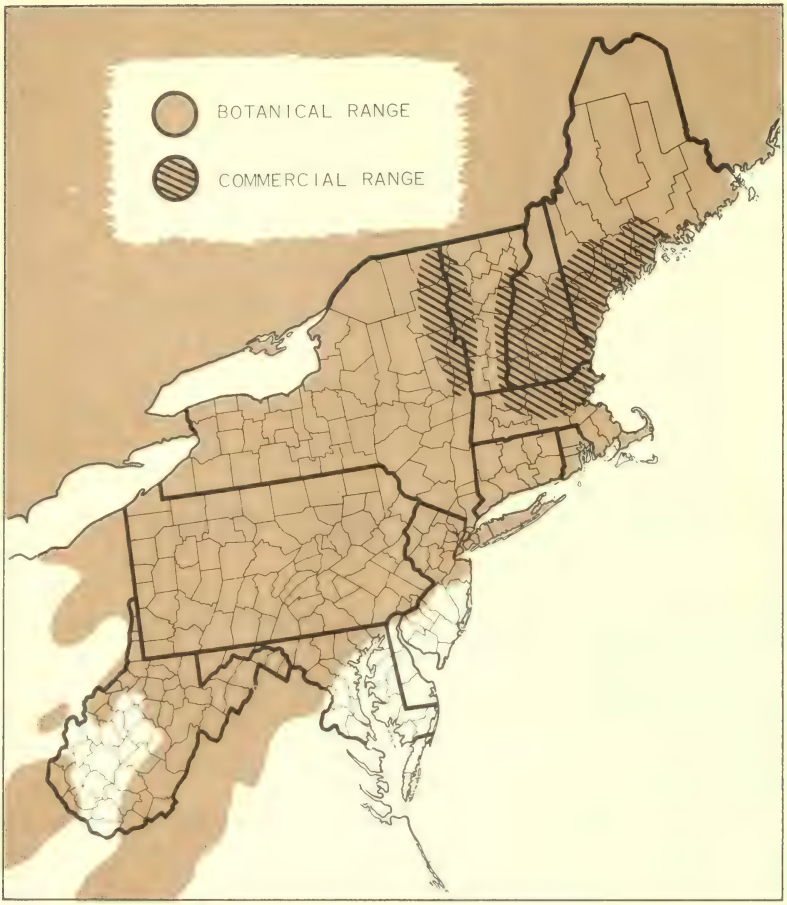


Figure 1.—The botanical and commercial ranges of eastern white pine (*Pinus strobus* L.) in the northeastern United States.

buildup that can help in deciding *when* to begin control treatments. This report does not cover in detail the various control methods and techniques. Other publications are available that deal with *how* to control the weevil.

No attempt has been made to acknowledge every scientific contribution to this subject; only a few sources are cited. More than 100 scientists have published studies on the white-pine weevil or on related problems. Each has added something to our present understanding, and it is the sum of these contributions that makes this report possible.

CONTROL INFORMATION

THE BIOLOGY OF WEEVIL INJURY

The Tree

Eastern white pine (*Pinus strobus*, L.) is a widely distributed and commercially important conifer that is native to the Northeastern United States. The natural botanical range of the species includes southeastern Canada, the Lake States, the Northeast, and the Appalachian Mountains as far south as Georgia (fig. 1). In the Northeast it is commercially important and is a predominant feature of the landscape in southwestern Maine, southern New Hampshire, northeastern Massachusetts, and in the northern drainage of the Hudson River in New York.

Though found on a variety of sites, white pine is likely to predominate permanently only where the competition offered by more tolerant species is not great. This tree is capable of high rates of growth, and it tends to maintain growth longer in life then most other conifers. In the Northeast, white pine is found in virtually pure stands; as the major component of stands that also contain significant quantities of hemlock, or of red oak and white ash; and as a moderate to minor component of many spruce-fir, northern hardwood, and central hardwood stands.

The Insect

The white-pine weevil (*Pissodes strobi* (Peck)) (fig. 2) is found throughout the botanical range of white pine. This small brown snout beetle attacks many conifers, both native and exotic (Craighead 1950), but white pine is its principal host.

Figure 2.—The white-pine weevil (*Pissodes strobi* (Peck)).

Adult weevils hibernate during winter in the pine duff of the forest floor. They emerge the next spring, usually some time between March and May. Emergence has been shown to be correlated with warming air temperatures expressed as cumulative degree-days (Godwin and Bean 1956). Mating may occur in the fall, but typically takes place after emergence in the spring (Jaynes 1958).

Soon after emergence, the weevils move toward the terminal growth of pine trees to feed and lay eggs. Weevils tend to move away from the ground and toward light during this period (Sullivan 1959); and they are strong flyers, so their movement is not limited to crawling. Female weevils may deposit several eggs per day for 2 months or more during May, June, and July. The eggs are inserted in small cavities chewed by the adult female in the bark of the previous year's terminal growth. Larvae hatch from these eggs in a week or 10 days, feed in the inner bark of the leader, pupate, and emerge as adults in the late summer.

Rather little is known about white-pine weevil population dynamics except that the general pattern is one of establishment, build-up, and continuation at a more or less high level of abundance.

Susceptibility of Pine

Not all pine trees are equally apt to be attacked by the white-pine weevil. Weevils tend to prefer vigorous pine trees with thick-barked leaders, and trees that are tall in relation to their neighbors (Kriebel 1954). This preference helps to explain why dominant and co-dominant pines are attacked more frequently than pines that are suppressed or overtopped. Weevils require coniferous duff for an overwintering site, and a scarcity of duff may limit weevil abundance; so this may explain in part why pines intermixed with hardwoods are not attacked so frequently as pines in pure stands.

There is some evidence that genetically controlled differences in susceptibility exist among eastern white pine trees. Provenance tests indicate that certain geographic ecotypes of pine may have a genetic resistance to weevil attack (Wright and Gabriel 1959). However, genetic differences appear to be small in comparison with environmental effects.

Figure 3.—Symptoms of weevil injury. A, terminal growth drooping after weevil larvae have attacked the internode below. B, weevil-caused crooking in young pine. C, crooking and forking in pole-size pine. D, an enclosed weevil-killed leader stub on a mature pine, sometimes the only evidence of injury that remains.

A

C

D

Response to Attack

The first evidence of weevil attack are small drops of resin that form on the leaders after the weevils have begun feeding and egg-laying. The weevil larvae, developing in and feeding on the leader, girdle the shoot and kill the growth above. This portion of the terminal growth gradually droops and turns brown, providing a positive symptom of injury (fig. 3).

The length of stem destroyed by the weevil varies. The last year's terminal growth (the site of egg-laying) and the current year's terminal growth are always destroyed by a successful attack. Occasionally 3 and even 4 years' growth is destroyed when larvae progress further down the stem than usual.

The lateral whorl below the lowest dead terminal continues the tree's height development, and the branches of this lateral whorl compete for the dominant position. New growth on the branches in this whorl tends to turn upward. Usually one branch soon outstrips the others and becomes the tree's terminal shoot. Generally the successful lateral is one of the largest ones with its base in the upper part of the whorl (Rhodes 1963). Not infrequently, however, growth is so evenly matched among competing lateral branches that forking of the main stem results. Actually, early dominance and forking are two extremes in response, and all gradations between can be found. Typically, competition persists long enough so that the branches that lose the race for the dominant position later appear to be attached at an unusually acute angle, and they may be unusually large if competition persists for any length of time.

The degree of injury may be significantly conditioned by environment. Dense, even-aged stands on good sites seem to show quicker and more complete recovery than is typical of other stand conditions.

THE INCIDENCE OF INJURY

Factors Related to the Incidence of Injury

The average incidence of weevil injury has been found to vary from year to year and from place to place. It also seems to be correlated with stand height, at first increasing and then declining as the stand grows taller. Within groups of young trees, taller individuals are injured more frequently than their shorter neighbors. Trees that have been weeviled before also seem to be injured somewhat more frequently than those that have not.

Variations from Year to Year and from Place to Place

A recent survey of weevil injury to northeastern pine plantations provides some indication of the regionwide average variation in injury incidence from year to year[1]. This cooperative survey was initiated by the Bureau of Entomology and Plant Quarantine in 1951, and was later transferred to the Division of Forest Insect Research of the Northeastern Forest Experiment Station, and was carried on annually in most states until 1957.

Each year, selected white pine plantations in eight northeastern states were re-examined for weevil injury. The average percent of trees currently injured in all stands examined varied from 2.7 percent in 1952 to 7.4 percent in 1955. The trend is generally upward in this group of young stands because weevil populations are still building up. Stands were also grouped by total height, and an average injury rate was computed for each height class and each year. The change in average rate from year to year for stands of a particular height class gives a better indication of general yearly variations in insect activity. The general level of weevil injury, as indicated by this measure, does vary to some extent from year to year (fig. 4).

[1] Lowe, J. H. Jr., and W. E. Waters. SURVEY OF WHITE-PINE WEEVIL DAMAGE IN PLANTATIONS IN THE NORTHEAST, 1951-57. Unpublished report. U.S. Forest Service. Northeast. Forest Expt. Sta., 8 pp., 1959.

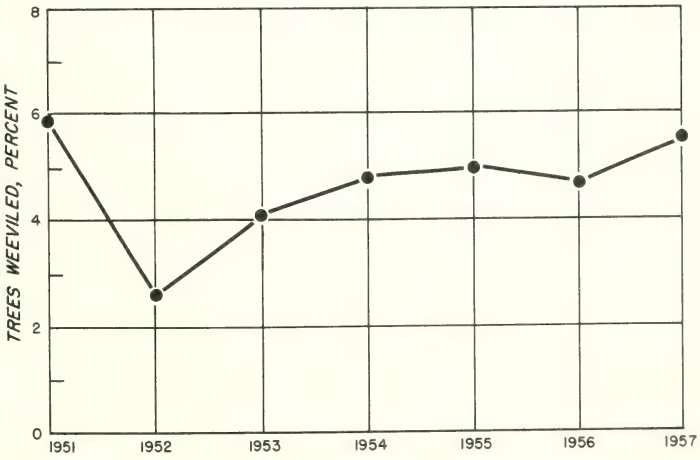


Figure 4.—Variation in current weevil injury from year to year in 4.5- to 6.4-foot-tall pine plantations in the Northeast, 1951-57.

Differences in the incidence of cumulative injury from place to place seem to be greater than year-to-year differences. A study of weevil-caused volume loss in New Hampshire (Marty 1959) showed that the average number of injuries discernible in the first 40 feet of bole of standing sawlog-size pines varied from 2 to 4½ among 12 small groups of pines within a 2-county area. Marked differences in the incidence of injury from place to place for young stands also have been noted (MacAloney 1930).

The existence of place-to-place differences in injury incidence raises the possibility of rating areas according to the general or long-term weeviling hazard they have shown. Foresters are often able to pinpoint areas of particularly high or low hazard on the basis of general observation alone. Further experience, coupled with sampling of injury rates, may suffice to establish generalized hazard zones, which could be of value in guiding control activities.

Variations Related to Absolute Tree Height

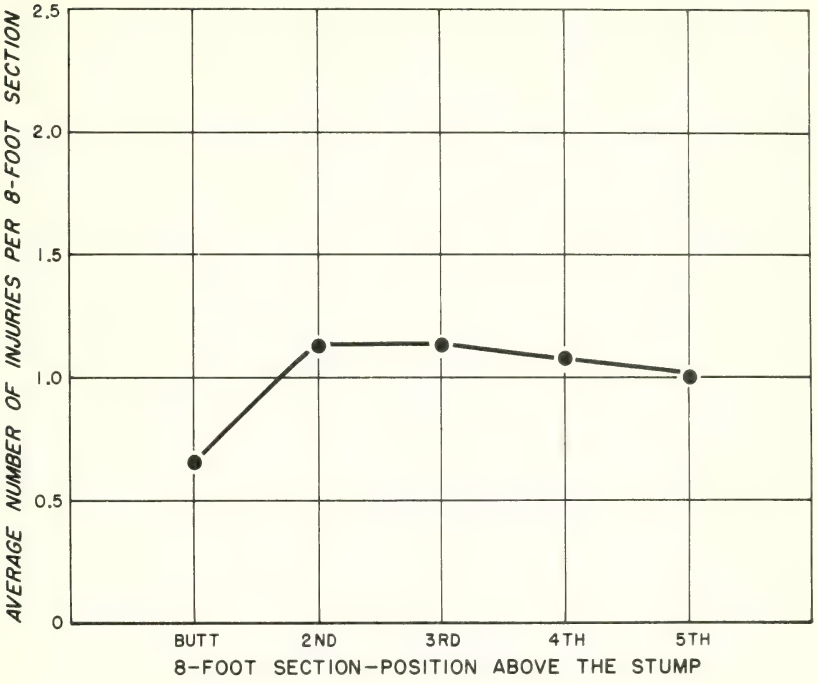
The New Hampshire volume-loss study also disclosed a difference in the average number of injuries in various sections of the bole. For these stands, discernible bole injury was generally light in the first 4 to 8 feet of the bole, then increased in the next 16 feet, but decreased in the logs above (fig. 5). This same pattern has been found in other studies as well (Connola and Wixson 1963).

Lowe and Waters[1] have suggested that the eventual decline in bole injury may be due to the increasing proportion of injuries that are diverted to the extra leaders produced by weevil injury (leaders that eventually become unmerchantable stems or branchs) rather than to the merchantable bole (to which the injury count was restricted in the aforementioned study). There may also be other changes in stand characteristics and weevil-population characteristics that take place as the trees grow in height, which contribute to this effect.

The Amount of Crop Tree Injury That Can Be Prevented by Control

Very little information about injury incidence in sawtimber trees is available, yet some estimate of the average number of injuries to anticipate under different conditions of weevil hazard is needed. Butt-log injuries averaged 1¾ per tree for the sample plots of sawlog-sized pines studied in New Hampshire and subsequently

Figure 5.—Weevil injury at different heights in the boles of sawtimber pines in New Hampshire.



in other northeastern states. Plot averages for butt-log injuries ranged from ¾ per tree to more than 3 per tree. Plot averages for second-log injury ranged from 1½ to 3, with a mean of 2¼.

In areas of high hazard, weevil injury usually begins earlier, develops faster, and reaches greater intensity than in areas of lower hazard. In areas of high hazard, then, butt-log injury may be much more serious than elsewhere. Differences in the amount of injury in the second log are probably less pronounced, although still significant.

All injury is not preventable with today's control techniques. There is likely to be some injury of treated trees, especially where weevil hazard is high. However, this unpreventable injury should not be great where control is properly done.

Estimates of the number of bole injuries that will be prevented by control are given in table 1 for three levels of hazard, in the butt log and the second log. Table 1 should be looked at as a definition of three levels of hazard. There is reason to believe that many white pine plantations will be subject to high hazard rates of in-

jury, as these are defined in table 1. Many natural stands are subject to lower injury rates. Most stands, planted or natural, will be subject to an injury rate somewhere within the range of this table. However, it is not known how prevalent the various hazard levels are throughout the Northeast. Specifically, it would be improper to assume that the medium hazard level of table 1 is the most frequently occurring hazard level.

Table 1.—Definitions of three levels of weevil hazard based on the number of injuries per log

Weevil hazard	Number of preventable injuries			
	Butt log		Second log	
	Average	Range	Average	Range
Low	½	0-1	1¼	0 -1½
Medium	1½	1-2	2	1½-2½
High	2¾	2+	2¾	2½+

The Distribution of Attacks Within Stands

Careful evaluation of injury patterns in the white pine plantations examined in the plantation survey has provided evidence of the importance of relative height and past injury on the distribution of current injury within these stands of pine. When little injury occurs in a pine plantation, most of it occurs in the tallest trees. As injury rates increase, a greater proportion of trees of lower heights are injured, but the greatest proportion of injuries still occurs in the taller trees (fig. 6).

The plantation survey also showed that trees that have never been weeviled before suffer less than their share of current injury. For example, when one-half of the trees in a plantation have never been weeviled, these never-weeviled trees suffer only 37 percent of the current injury, on the average. Sixty-three percent of the new injury occurs on the half that has already been injured. The distribution of attacks is thus related to the proportion of trees still unweeviled (fig. 7).

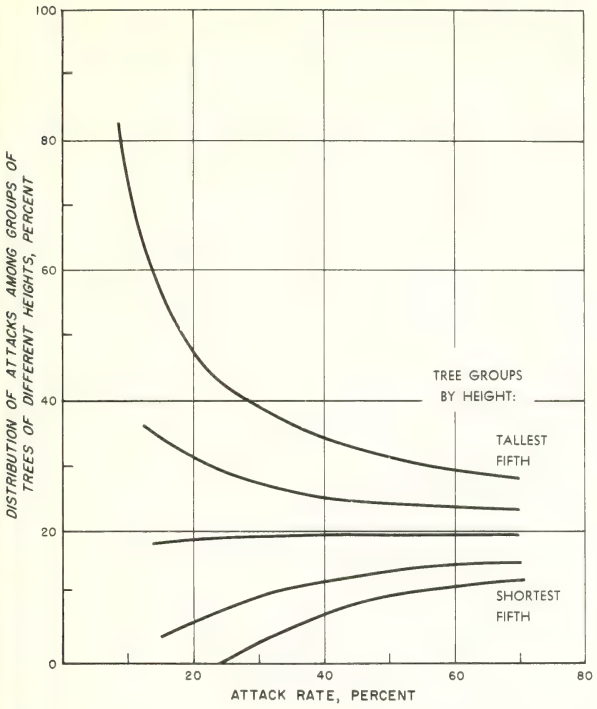


Figure 6.—The relation between attack rate (proportion of all trees in a plantation that are currently attacked) and the proportion of the attacks occurring on trees in five relative height classes.

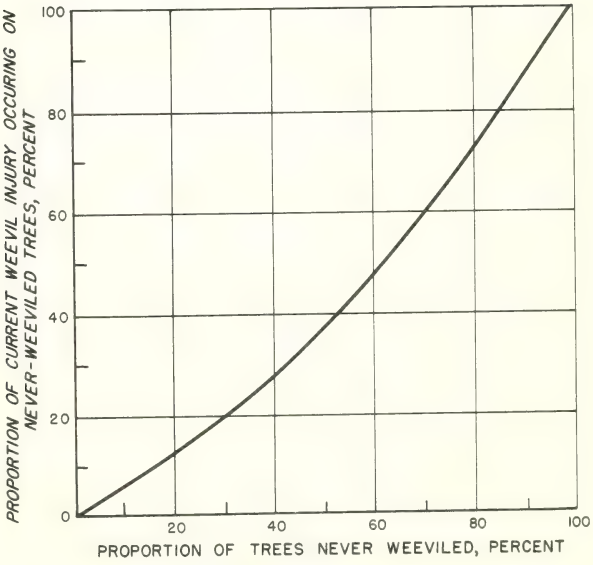


Figure 7.—The relation between the proportion of all trees in a plantation that have never been weeviled and the proportion of attacks that occur on these never-weeviled trees.

The Pattern of Injury Buildup

The first weevil attacks that occur in a young stand are caused by insects that have immigrated from surrounding areas. If the new stand provides suitable conditions, such as adequate duff for overwintering and not too much overstory shade to discourage egg-laying, gradual buildup of a resident weevil population takes place. This population buildup is accompanied by a coincident buildup in injury.

The typical trend in injury buildup is not perfectly regular or smooth; rather, rapid increases alternate with more modest increases and sometimes temporary declines. However, an average pattern has been observed in the plantation survey. This reveals that when the rate of attack is low, as when the weevil population is just becoming established, the increase in the rate of attack the following year is apt to be relatively great. When the attack rate is high, on the other hand, the increase in attack rate the following year is apt to be small.

These relations describe a typical pattern of injury buildup. At first the injury rate increases rapidly from one year to the next; then it increases more and more slowly until it is fluctuating about

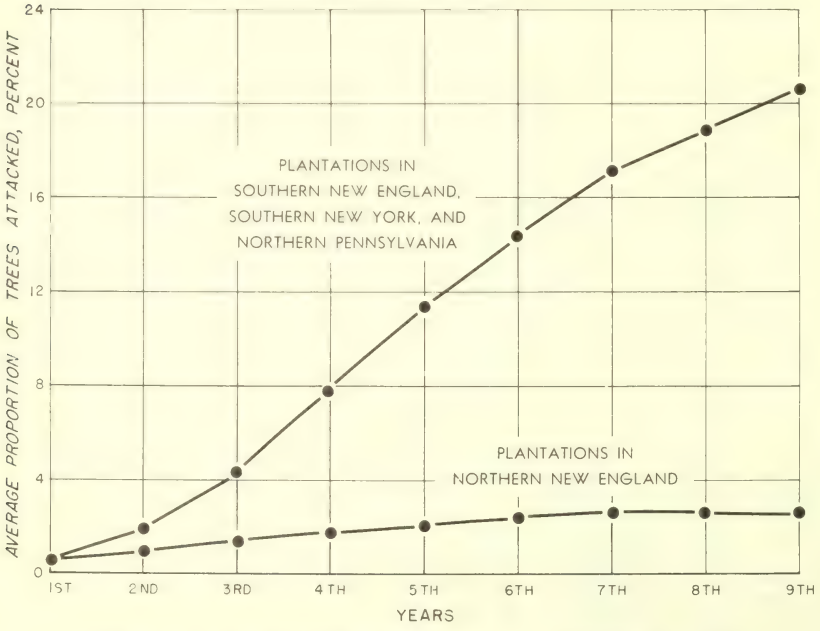


Figure 8.—Two average patterns of injury-rate buildup found among northeastern pine plantations.

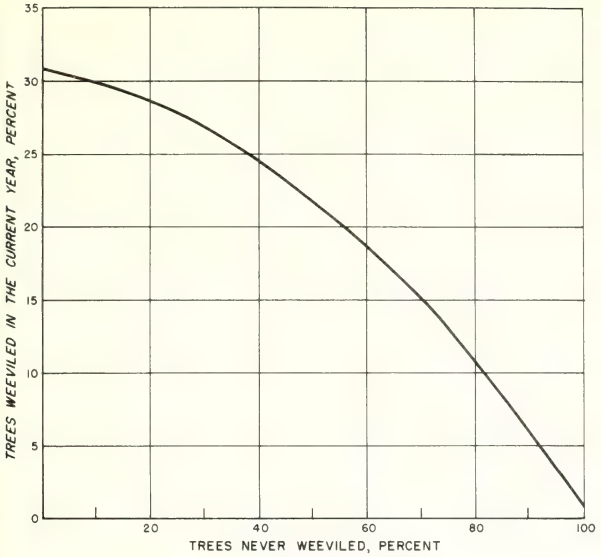


Figure 9.—The average relationship between the percent of trees currently injured, and the percent of trees that have never been weeviled, in northeastern pine plantations.

a rather stable and continuing rate that differs from stand to stand, from place to place, and from year to year. We believe that this equilibrium injury rate probably reflects the maximum weevil-population density that the area can support, and is another measure of hazard. Two curves (fig. 8) depict the injury-rate buildup in two quite different conditions: rapid buildup to a high equilibrium rate, typical of plantations in southern New England, northern Pennsylvania, and southern New York; and a more gradual buildup toward a low equilibrium rate typical of northern New England pine plantations.

In the plantations surveyed, as the injury rate increased in successive years, the number of never-weeviled trees declined. Consequently there is a relationship between the current rate of attack and the proportion of trees never-weeviled at any point in time (fig. 9).

These data from plantation pine 16 feet and shorter do not show the eventual decline above 20 feet in injury rate, discerned in studies of larger trees.

Other Causes of Terminal Injury

Other agents can cause terminal injury in pine. Frost damage, whipping by hardwood saplings, and attack by various animals and birds may all be important sources of terminal injury in particular localities, and will be present to some degree in most stands. For

these reasons even elimination of the white-pine weevil will not completely eliminate terminal injury. It is important to be sure that the weevil is the major cause of injury before weevil control is prescribed.

VOLUME LOSS

The Region as a Whole

Weevil injury has continued unchecked for as long as we know, and in many cases the most heavily damaged trees and stands have been left uncut. For example, in 1952 the New Hampshire sawlog inventory was only 60 percent of what it could have been if there had been no weevil injury (Waters et al 1955). Two billion board feet of timber, made unmerchantable by weevil injury, were occupying valuable growing space. Volume loss continues today wherever pine owners fail to control weevil injury. Annual losses for the Northeast as a whole may be 50 to 100 million board feet per year, with a total value of perhaps a million dollars.

How Injury Affects Recoverable Volume

In 1952 Waters and others (1955) made a careful appraisal of more than 100 sample plots located in New Hampshire white pine stands. Some of the stands sampled were of poletimber size; others held sawtimber. By comparing weeviled pines with pines free of weevil injury, it was possible to determine average levels of loss due to weevil injury, and to determine the way that injury affected recoverable volume.

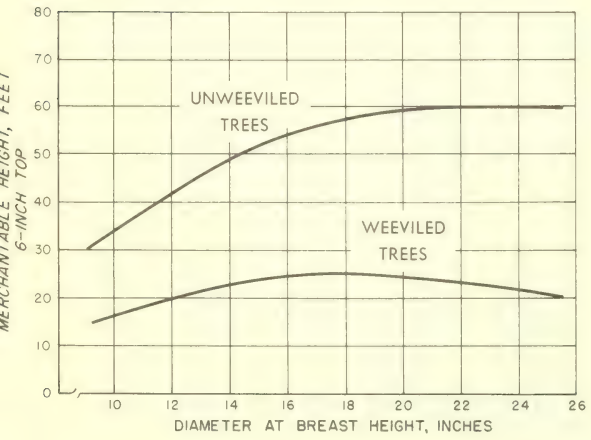


Figure 10.—Average merchantable height of weeviled and unweeviled white pine in New Hampshire, 1952. (After Waters et al, 1955.)

The most striking influence of weevil injury was the reduction in merchantable height that it caused (fig. 10). Loss in merchantable height caused all the volume loss noted in pole-size trees, and most of the volume loss in sawtimber trees. Injury also caused sweep and crook within merchantable length, which accounted for the remaining volume loss in sawtimber trees. Average volume losses for the pines sampled in New Hampshire were 13 percent in pole-size trees, 40 percent in the sawlog portions of sawtimber trees, and 70 percent in those portions of sawtimber trees above sawlog limits.

Injury Intensity and Volume Loss

The number and position of weevil injuries are important in determining volume losses. In general, the more frequently the tree is injured, the greater the volume loss will be. The position of an injury on the bole is also important. Injuries above normal merchantable height cause no loss. Injuries in the top logs cause relatively little loss because they affect only a small portion of the tree's volume. Injuries located in the butt log are often the most serious because they are in the section of the tree that has the greatest volume.

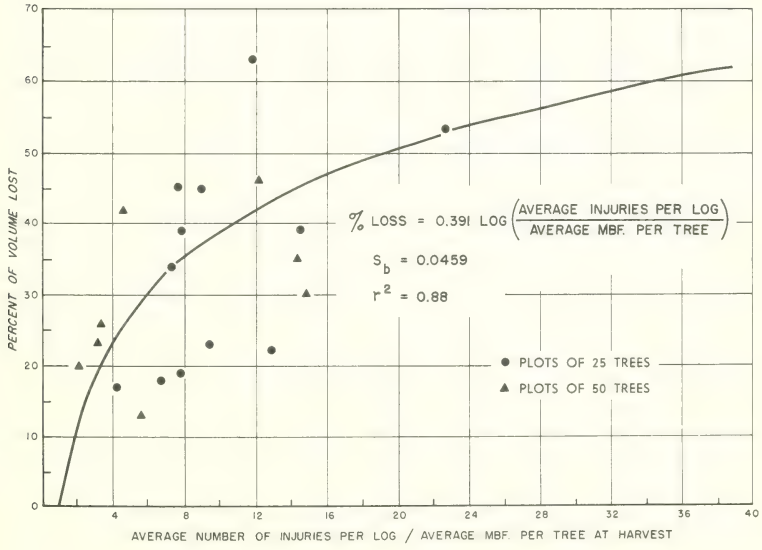


Figure 11.—A relationship between volume loss, injury intensity, and tree size.

Two studies of sawtimber pine stands have been made in an attempt to determine the relationship between the incidence of bole injury and volume loss. The initial study has been mentioned above and is reported elsewhere (Marty 1959). The second study confirmed the results of the first and led to a somewhat better way of expressing the relationship (fig. 11).

In these studies, 20 plots of sawlog-size pines, scattered throughout the Northeast, were examined. Plots were made up of either 25 or 50 trees. All 20 plots had been affected by weevil injury, and volume loss for individual plots varied from 22 percent to 63 percent. Such limited research cannot give exact estimates of effects, but analysis did show that both the average number of injuries per log and tree size at harvest were significantly correlated with volume loss. Other factors, both intrinsic and extrinsic, also influence loss importantly, but these factors have not yet been studied quantitatively.

Average Volume Saved

The volume-loss relationship can be used to predict the amount of volume that can be saved by control under different conditions of weevil hazard, as these are defined in table 1. Table 2 shows the average board-foot volume saved per tree by control in the first and second logs for each level of weevil hazard, and for a number of different harvest diameters (d.b.h.). Notice that the volume

Table 2.—Estimates of the volume saved by control under different hazard conditions[1] for trees of various harvest d.b.h., in board feet

Tree d.b.h., inches	Butt log				Second log			
	Normal volume[2]	Volume saved when hazard is—			Normal volume[2]	Volume saved when hazard is—		
		Low	Medium	High		Low	Medium	High
10	36	16	21	24	20	9	12	13
12	56	19	27	31	32	14	15	18
14	78	20	32	37	46	20	19	22
16	106	21	36	45	62	12	21	26
18	136	19	39	49	81	11	23	29
20	171	14	38	53	104	8	23	32

[1] Hazard conditions are defined as to expected incidence of preventable injury according to ratings in table 1.

[2] Normal volumes, taken from Bickford (1951) for a form class of 78, assume no weevil injury.

that can be saved by control usually increases with harvest d.b.h., but not as rapidly as normal volume increases. This reflects the fact that for any given level of injury, the percent of normal volume lost declines as normal volume increases. Given the number of crop-trees per acre and their harvest d.b.h., per-acre volume savings can be determined from table 2.

LUMBER DEGRADE

Comparative Importance

Weevil injury causes two important forms of economic loss. The first, discussed above, is loss in merchantable volume, which is easy to see in most injured stands. The second type of loss is a reduction of the quality in the portion of the injured tree that still is merchantable. Loss in quality becomes apparent only after the tree is cut and sawed. Its effect is to lower the grade of some of the lumber recovered from the injured tree.

Although lumber degrade cannot be seen in standing trees, it is much more important economically than is volume loss. Ostrander and Stoltenberg (1957) concluded that reduction in lumber quality due to weevil-caused defect is substantial. They found losses of $2 to $34 per thousand board feet, depending on the number of injuries per log.

The average rate of weevil injury for trees now being harvested in the Northeast is probably between 1 and 2 injuries per 16 feet of merchantable bole. Our studies indicate that this means an average decrease in quality index[2] of somewhere between 6 and 14 points. At 1961 prices—and assuming that the changes in the supply of the various grades if no weeviling had occurred would not affect their prices—this constitutes an average loss of $10 to $24 per thousand board feet of white pine produced. With rates of production for the Northeast averaging 600 to 700 million board feet per year (1946-56), the economic loss from weevil-caused lumber degrade may be more than $6 million each year.

[2] Quality index (QI) is an expression of lumber grade yield. The higher the QI, the better the grade yield of lumber. QI is derived by determining for each lumber grade its price expressed as a percentage of the average price of No. 1 and 2 Common lumber, and multiplying these relative values by the volumes of lumber in each grade forthcoming from a tree, a log, or a run of logs. QI is usually expressed as a percent. For example, a QI of 127 percent indicates that a grade mix of lumber on the average was worth 127 percent as much as an equal volume of No. 1 and 2 Common lumber.

How Injury Affects Timber Quality

Lumber-recovery studies have shown that several lumber defects are caused by weevil injury. Among these are cross-grain, red rot, large branch knots, and loose knots (Ostrander and Foster 1957). These defects arise from the heavier and more acutely angled branching that follows weevil injury, and from a gradual enclosing of the dead weeviled leader (fig. 12).

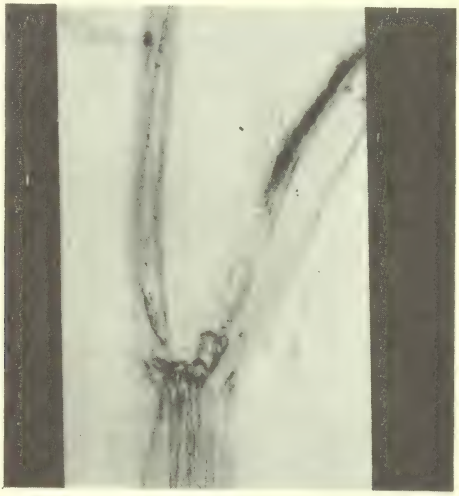


Figure 12. — Weevil-caused lumber defects.

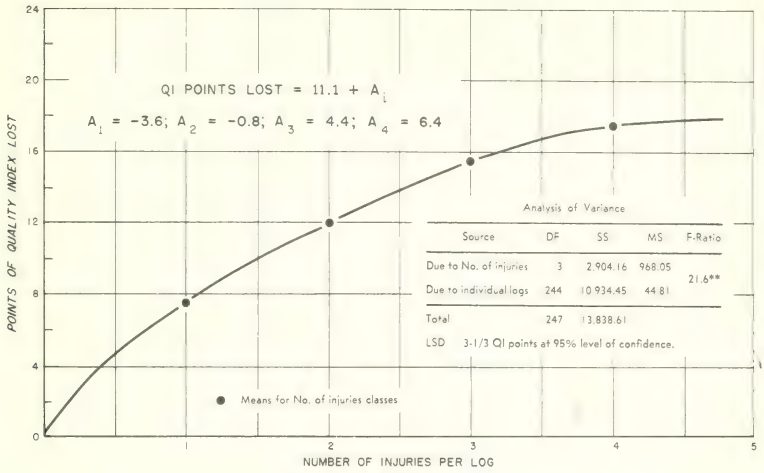
Generally, weeviling defects have been found in mill studies to reduce board quality by one grade. However, in some cases weevil-ing may cause no degrading defects: or it may cause enough de-fect to reduce lumber quality as much as three grades.

The Influence of Number of Injuries on Quality Loss

An examination of 248 logs processed at one mill in Maine showed that the average loss in quality index due to weevil injury increased significantly with the number of injuries per log (fig. 13). Quality index declined an average of 7½ points for logs with a single weevil injury, about 12 points for 2 injuries, 15½ points for 3 injuries, and 18 points for 4 injuries.

These data indicate that as the number of injuries increases there is a somewhat less than proportional decline in quality index. The study did not disclose any marked differences in loss for logs of different sizes.

Figure 13.—A relationship between number of injuries and lumber degrade. Class means are connected by a freehand curve.



The Improvement in Grade Recovery Due to Weevil Control

It is possible to construct estimates of the average quality index increase due to control that would occur given the three levels of weevil injury assumed in table 1. Table 3 shows the average increase for the first and second log in each hazard class. Remember that these increases in quality index apply to the entire volume of protected logs, not only to the volume that would otherwise be lost. The volume that would have been recovered even without control is also raised to the new quality level.

Table 3.—Estimated increases in lumber quality due to weevil control, for three levels of hazard

Weevil hazard[1]	Average increase in lumber grade recovery due to control in the—	
	Butt log	Second log
	Quality index	*Quality index*
Low	4.5	9.0
Medium	10.0	12.0
High	14.5	14.5

[1] Injury rates assumed are given in table 1.

THE VALUE OF CONTROL

How White Pine is Used

The value of weevil-caused losses—and hence the potential value of weevil control—depends upon the value of white pine timber. The value of pine timber, in turn, depends upon the demand for it at any given time, and the supply made available by landowners and managers.

Most eastern white pine is converted into lumber; but some pine is pulped, and small amounts are used in other ways (U.S. Forest Service 1954). Eastern white pine lumber has three major uses: construction, containers, and manufactured specialty products. It is used as sheathing, subflooring, and other structural elements in light construction; for packaging and crating of various sorts; and to make patterns and flasks, millwork, furniture and fixtures, boot and shoe findings, matches, toys, athletic equipment, and other specialty products.

These uses take different grades of white pine lumber. The lower grades are generally suitable only for construction and containers. Manufactured products require higher quality lumber. The competition faced by white pine lumber producers in the Northeast also varies from one grade to another. The lower common grades of white pine can be replaced readily in construction and containers by other species of lumber and by plywood and nonwood products such as gypsum board. On the other hand, the better grades of white pine lumber are a preferred material that commands premium prices for many manufacturing uses. Competition in the higher grades comes from eastern white pine produced in the Lake States and western white pine and sugar pine from the Western States.

Stumpage Markets in the Future

Market prospects are considerably more favorable for good-quality than for poor-quality stumpage (King et al 1960, Holland 1960). The ease with which poor common lumber can be replaced by other materials severely limits market outlets and depresses prices for these grades, and so for poor-quality stumpage as well.

The average lumber grade mix currently produced by the white pine industry of the Northeast is: Selects 3 percent, No. 1 and No. 2 Common 12 percent, No. 3 Common 35 percent, and No. 4 Common 50 percent. Trees harvested in the Northeast average about 12 inches in diameter. Published projections (Holland 1960, King and others 1960) for this run-of-the-woods stumpage fore-

tell a 50-to-75-percent increase in stumpage prices over the next 40 to 60 years, based on likely trends in population, per-capita lumber consumption, construction activity, lumber-production costs, and stumpage supplies. According to these projections, stumpage of the current average quality and size, which sells now for about $15 or $20 per thousand board feet, may be worth approximately $25 to $35 per thousand board feet when stands now suitable for weevil control become mature.

Influence of Average Tree Size and Quality

In the future, owners who sell stumpage that is of better-than-average quality and of larger-than-average size may be able to sell their stands at a premium. How much more than the going price they receive will depend on competitive conditions in their stumpage market when they sell, and on how much better their stumpage is than the average.

Logging and milling studies (Dowdle 1962) carried on at the Northeastern Station indicate that it now costs about $13 more per thousand board feet to process logs from pine trees 10 inches d.b.h. than from 20-inch trees. Large trees will probably continue to be cheaper to log and mill than small ones, and the differences in cost may be even greater in future years. Because of these differences in processing cost, stumpage made up predominately of trees 16 inches d.b.h. and larger may be worth $10 more per thousand board feet than will the more usual 10-to 14-inch stumpage.

Those who practice weevil control are more likely to produce stumpage of better than average quality. Weevil control in the butt log is quite likely to increase a pine stand's average lumber grade yield by 5 points on the quality index. If pine lumber prices increase somewhat in the future, an added point of quality could easily be worth $2 per thousand board feet to the processor.

In areas where the competition for stumpage remains slight, stumpage prices may stay at virtually the same relative level as today. Pine owners will not be offered much of a premium for superior stands in these areas. But for the major pine-producing areas, where the processing industry is concentrated, and where there is likely to be brisk competition for better-than-average stumpage, the picture should be brighter.

Future Price Assumptions

Two different assumptions about future prices are used here because prices and pricing policies may vary so much from one area

to the next. You can use the price assumption that you feel will be closest to the mark for your area.

The first assumption is that the stumpage market will stay much the same as it is today. Run-of-the-woods stumpage will sell for $20 per thousand board feet, and one-quarter of the additional value of better-than-average size and quality will be paid to stumpage sellers. The second assumption is that the general level of stumpage prices will increase by 50 percent, and that the pine owner will receive one-half of the additional value of better-than-average stumpage. Table 4 shows prices and differentials in dollar terms for these future market assumptions.

Table 4 also shows the total value of control. Total values are appropriate for the public investor who counts all returns to weevil control regardless of to whom they accrue. Stumpage prices are appropriate for the private pine grower who can expect to be paid only a part of the value he adds by weevil control.

Now it is possible to calculate the dollar stumpage returns added by control, for each hazard class, harvest d.b.h. and future price level, and for both butt-log and second-log control. These are shown, on a per-crop-tree basis, in table 5. This assessment of the value of control ignores the increased volume and quantity of thinnings in protected stands that will receive commercial thinning, and it somewhat understates control returns in these cases.

Table 4.—Stumpage value and price assumptions

Value elements	Stable markets[1]		Rising markets[1]	
	Total value per 1,000 bd. ft.[2]	Stumpage price per 1,000 bd. ft.[2]	Total value per 1,000 bd. ft.[2]	Stumpage price per 1,000 bd. ft.[2]
Base price	$20.00	$20.00	$30.00	$30.00
Add for stumpage of 16-inch d.b.h.	10.00	2.50	10.00	5.00
Add for each QI point saved	2.00	0.50	2.00	1.00

[1] Stable markets assume going prices like those of today with one-fourth of the size and quality differentials being passed on to the stumpage seller in the form of higher stumpage prices. Rising markets assume 50-percent increase in going prices and a doubling of the proportion of the size and quality differentials that are passed on to the stumpage seller.

[2] Total values are appropriate for public investors who count all returns regardless of to whom they accrue. Stumpage prices are appropriate for the private nonintegrated stumpage producer who can expect to be paid only a part of the value he adds by weevil control.

Table 5.—Estimated returns per crop tree for weevil control

Weevil hazard class	Crop-tree d.b.h. at harvest (inches)	Returns from butt-log control				Returns from second-log control			
		Stable markets[1]		Rising markets[1]		Stable markets		Rising markets	
		Total value added[2]	After-tax return[2]	Total value added[2]	After-tax return[2]	Total value added[2]	After-tax return[2]	Total value added[2]	After-tax return[2]
Low	10	$0.64	$0.30	$0.80	$0.48	$0.54	$0.20	$0.63	$0.34
	12	.89	.37	1.08	.62	.86	.32	1.00	.53
	14	1.10	.43	1.30	.71	1.22	.45	1.42	.76
	16	1.58	.53	1.80	.91	1.48	.41	1.60	.74
	18	1.79	.55	1.98	.96	1.79	.46	1.90	.84
	20	1.95	.53	2.10	.95	2.12	.48	2.20	.92
Medium	10	1.14	.45	1.35	.74	.72	.27	.84	.45
	12	1.66	.62	1.93	1.03	1.06	.37	1.21	.62
	14	2.20	.77	2.52	1.31	1.48	.49	1.67	.84
	16	3.20	1.01	3.56	1.74	2.11	.63	2.32	1.11
	18	3.89	1.17	4.28	2.05	2.63	.75	2.86	1.34
	20	4.56	1.28	4.94	2.28	3.19	.86	3.42	1.55
High	10	1.52	.56	1.76	.93	.84	.31	.97	.51
	12	2.24	.77	2.54	1.31	1.28	.44	1.46	.75
	14	3.00	.98	3.37	1.68	1.78	.58	2.00	1.00
	16	4.42	1.34	4.88	2.34	2.58	.78	2.84	1.36
	18	5.41	1.56	5.90	2.77	3.23	.93	3.52	1.65
	20	6.55	1.82	7.08	3.26	3.98	1.12	4.30	1.97

[1] Stable and rising market conditions are defined in table 4.

[2] Total value added counts all returns regardless of to whom they may accrue, and is not reduced for income-tax liabilities. After-tax return reflects only the addition to stumpage income a private grower might expect under each market condition, less 25 percent to reflect a typical level of income-tax liability.

Returns are not difficult to calculate from the estimates already presented. For example, a tree that was protected from weevil injury while its butt log was formed, is in an area of medium hazard, will be harvested when it is 14 inches d.b.h., and will be sold in a stable market, will have 32 board feet more volume than it otherwise would have had (table 2); and the quality index of the butt log will have been increased by 10 points (table 3). The stumpage value of the volume saved is $20 per thousand board feet, and the quality added by control has a total value of $2 per quality point per thousand board feet (table 4).

The added stumpage value per tree can be calculated in two steps:

1. (Volume saved) (unit value of volume saved)
   (32 board feet) ($0.020)=$0.64
2. (Total volume) (QI increase) (unit value of quality)
   (78 board feet) (10 points QI) ($.002)=$1.56

The sum of these two elements gives a total value of $2.20 in this case.

The Effect of Taxes

Private investors must give up some of their added income in the form of taxes. Table 5 shows the added stumpage return per tree after this income is decreased by 25 percent for taxes.

CONTROL METHODS AND COSTS

Methods of Control

Weevil control means reducing the amount or severity of injury caused by the weevil. A number of techniques and prescriptions for control have been suggested and developed during the last 25 years. These techniques fall into three main categories: cultural, biotic, and chemical. A brief review of these may serve to underline the great variety of techniques available, and the diversity of control principles involved.

Cultural Control

A number of silvicultural prescriptions were early suggested, aimed at creating or maintaining conditions that lessen weevil attack or promote post-injury recovery (Pierson 1922). These were based on (1) obtaining partial shading of the pines with a hardwood overstory to reduce the frequency of attack, or (2) maintaining high density of pines to cause injured trees to straighten more

quickly. These prescriptions are less than ideal because pine growing under an overstory or at high density develops merchantable volume more slowly than pines that have adequate growing room. So these control techniques can lead to loss of growth, just as weeviling does.

Another cultural method that has been suggested takes advantage of natural differences in tree condition in reclaiming weeviled pine stands (Cline and MacAloney 1931). This technique, developed for severely injured plantations, calls for selecting the least severely injured pines for crop-trees with due regard for spacing, and treating surrounding trees to free these crop-trees for rapid growth and development. In plantations the least-injured trees are often found in the lower crown classes. Pruning of all but one of the laterals in the topmost whorl of live branches will reduce crook and eliminate forking (Rhodes 1963).

Finally, a sanitation technique—removal and burning newly weeviled leaders—has been used in young pine stands to control infestation. This method is at least partially effective, but it is costly as compared with chemical control.

Biotic Control

Recently much interest has been shown in using other organisms to control insects. Micro-organisms such as viruses, bacteria, protozoa, and fungi are all being tried as controlling agents for various insects. Natural insect parasites and predators are also being studied. If it is possible to find a biotic vector that is effective in controlling the weevil, that is easily propagated, and that can be successfully distributed in selected locations, then weeviling could be controlled effectively, cheaply, and with little or no danger to other forms of life.

Genetic manipulation of the weevil itself is a different sort of biotic technique, and this holds considerable promise. One such technique involves sterilizing and releasing male weevils which then compete with normal males in mating, and thus reduce the population in the next generation. Effectiveness depends on the ratio of sterilized males to normal males and to females, and the success of sterilized males in competing with normal males.

Chemical Control

At present the most successful and widely used techniques are those that employ chemical insecticides to kill adult weevils. In most chemical techniques, liquid insecticide is applied to pine foliage. Applications of granular insecticide to ground litter have

also been made to control weevil populations during hibernation.

Four ways of making foliar application have been developed: (1) drenching of leaders by means of portable compressed-air sprayers, (2) broadcast treatment of upper crowns with portable mist blowers, (3) with truck mounted mist blowers, and (4) with aircraft (Potts et al 1942, Crosby 1958, Connola et al 1955, and Hastings and Risley 1962).

In addition to these different methods of application, there are many different insecticides, carriers, spreaders and extenders, toxicant concentrations, rates of application, and timings of treatment. All these factors—and weather too—influence control success and the degree of danger to other organisms.

Finding the Cost of Control

No attempt is made here to analyze the costs of different control techniques that are now operational. At this writing, most people would probably choose as equipment a compressed-air sprayer (for control jobs involving less than 50 acres of young pine) or a mist blower (for larger ownerships and for contractors), and use aqueous solutions of DDT or lindane applied at 2- to 5-year intervals. But conditions from one ownership to another vary so much, and control techniques are developing so rapidly, that any analysis of these techniques would not apply generally, and would soon be out of date. If there is any question about the best technique in your particular case, you can decide on the basis of three factors that you will want to know in any case:

1. The per-acre cost of a treatment.
2. The number of treatments required.
3. Side effects of the control technique.

The cost per treatment is quite an individual affair; and it can vary widely from one manager or organization to the next, even when all employ similar techniques. Wage rates and subsidies are probably the most important cost factors. It is proper to include overhead expenses as well as direct costs in the cost estimate, and to deduct from the estimate any cost-sharing or subsidy payment (for example, ACP payments) anticipated. Cost-sharing and subsidy payments are available to the private investor, but not to the public investor; so the real cost of control will often be lower to the private investor. This tends to offset the private investor's tax load to a considerable degree. Cost per treatment for chemical weevil control in the Northeast usually has varied between $1 and $5 per acre.

The second cost factor—number of treatments—depends on

such factors as the length of time you decide to maintain protection, and on how frequently the stand must be re-treated to hold injury to an acceptable level. You can estimate the number of treatments easily enough if you estimate four things: (1) the stand's average height when you plan to begin control, (2) the stand's average height when you plan to stop control, (3) the average rate of height growth, and (4) the treatment interval required for your control technique and the hazard condition. So far, re-treatment usually has been required every 2 to 5 years in the Northeast. You can use table 6 to find the number of years it will be necessary to continue protection for the various combinations of rate of height growth and average stand height when protection begins and ends.

The final factor—side effects—can be treated only as a matter of judgment. Occasions do arise when one technique is less costly, but more dangerous, than another. You can obtain a good idea of the extra cost involved in choosing the safer technique by estimat-

Table 6.—Number of years during which protection against the weevil must be maintained[1]

Present average height of pine (feet)	Number of years protection must be maintained when the average rate of height growth in feet per year is—					
	1.0	1.2	1.4	1.6	1.8	2.0
	BUTT-LOG PROTECTION					
2	17	14	12	11	10	9
4	15	13	11	10	9	8
6	13	11	10	9	8	7
8	11	9	8	7	7	6
10	9	8	7	6	5	5
12	7	6	5	4	4	4
	TWO-LOG PROTECTION					
2	33	28	24	21	19	17
4	31	26	22	20	18	16
6	29	24	21	19	17	15
8	27	23	20	17	15	14
10	25	21	18	16	14	13
12	23	19	17	15	13	12

[1] Control is assumed to continue 1 year beyond the season in which crop-trees average 18 feet in total height for butt-log protection, and 1 year beyond the season that crop-trees average 34 feet for 2-log protection.

ing the cost per treatment and number of treatments for each as outlined above. You must then make a judgment about whether the added safety is worth the added cost.

Control Schedule Assumption

At this point it is necessary to distinguish between two kinds of control procedure. The first procedure involves choosing a number of pine trees per acre that are to be maintained in an unweeviled condition, and from which crop trees will later be chosen.

Treatments are timed so that control maintains at least this many trees unweeviled, but there is no decision about which particular trees these will be. In practice, these trees will probably be the slower growing ones, since short trees are usually among the last to be attacked (fig. 6). Thus the crop trees probably will not be the fastest growing pines in the stand, and they may not be the best individuals in other respects as well. This may have a long-term influence on the genetic character of subsequent reproduction, which should be kept in mind.

The second procedure would involve choosing crop-trees before control began, and timing treatments so that all or some proportion of these trees were maintained weevil-free. This is probably not a very workable system because it would be difficult to choose crop-trees when the stand may be no more than 5 or 6 years old; and

Table 7.—Assumed average control schedules for stands subject to three levels of weevil hazard[1]

Weevil hazard	Stand height when control begins	Treatment interval	Treatments
	Feet	*Years*	*No.*
	BUTT-LOG CONTROL		
Low	11	4	2
Medium	8	3	4
High	5	2	6
	SECOND-LOG CONTROL		
Low	18	5	3
Medium	18	4	4
High	18	3	5

[1] An average rate of height growth of 1.2 feet per year is assumed. Weevil hazard is as defined in table 1.

because it would require many more treatments to protect fast-growing, more susceptible pines from injury. Both the profit analysis and the scheduling analysis assume the first control procedure, although other procedures are possible.

A later section of this report covers in detail the problem of scheduling control in individual stands. However, it is necessary to make some guesses here about the average control schedule for stands subject to each of the three levels of weevil hazard, in order to determine average levels of profitability. It is assumed here that on the average, treatment will begin sooner and will be repeated more frequently where weevil hazard is high than where it is low. Table 7 shows these assumed average control schedules for each hazard zone.

CONTROL DECISIONS

The first section of this report has presented background information necessary to an understanding of weevil injury and its effects. A series of assumptions and estimates have been drawn from these data about injury rates, volume and quality losses, and control schedules. The next step is to build on these estimates and assumptions to develop specific scheduling and evaluation guides.

CHOOSING CONTROL SITES

Control Criteria

From the economist's point of view, young pine plantations and areas of natural pine reproduction should meet each of four criteria before weevil control is undertaken in them:

- Sawlog production should be one of the objectives of stand management.
- The intensity of weevil injury should have reached a point where control is needed to assure the desired number of damage-free crop trees at target height.
- There must be sufficient funds and manpower available to undertake control.
- Weevil control ought to be a reasonably profitable use of these funds and manpower.

The first criterion is important because weevil control probably pays off adequately only in stands that will be harvested for sawtimber. Pine pulpwood yields are reduced by weevil injury to some extent, but probably not enough to warrant control. Pines grown for Christmas trees might benefit considerably from weevil control, but this is not considered in this report.

The second and third criteria involve matters of timing. It does not seem wise to begin control sooner than is necessary, and it is not possible to undertake control if you lack the needed time and money. Ideally, control should be timed so that adequate funds and manpower are available, and so that control is neither premature or delayed.

The final criterion is profitability. From the economist's point of view, one should not invest in weevil control except in stands where it is reasonably profitable. Weevil control should promise about as good a return as could be expected for investing in some other management practice, in a non-forest activity, or in securities. People differ about what is reasonably profitable for them. Some demand very high returns; others are satisfied with lower ones. Like treatment costs, acceptable return is an individual matter that each must decide for himself on the basis of his own investment opportunities.

The purpose of what follows is to develop and present estimates of the profitability of control in many different circumstances. By using this information you can rank young pine stands in order of their profitability for weevil control and concentrate your control efforts in the ones that offer returns that you judge to be adequate.

The Factors that Determine Control Profitability

Here is a summary of the factors that influence the costs and returns to weevil control:

- Factors that determine stumpage value added:

  1. *Weevil hazard.*—This determines the number of injuries that can be prevented (table 1) and the degree to which lumber grade yield can be improved by control (table 3).

  2. *Target d.b.h. for crop trees.*—This, together with hazard, determines the average volume per crop tree that can be saved by control (table 2).

  3. *Number of crop trees per acre.*—This converts crop-tree volume and quality savings to a per-acre basis.

4. *Future stumpage price or value.*—This determines the stumpage income or value added by control (table 5).

■ Factors that determine control cost:

1. *Weevil hazard.*—This determines (for the purposes of this profit analysis) both the stand height when control begins and the average interval of time between treatments (table 7).

2. *Control period.*—This is defined by the stand's age when control begins and ceases (table 7).

3. *Treatment cost.*—This, with the other cost factors, determines the dollar amount and timing of control outlays.

A final factor, not mentioned before, must be taken into consideration in order to estimate rate of return to control.

■ The factor that relates control cost and stumpage value added:

Investment period.—This is given by rotation age less stand age at first treatment, and it determines the length of time that you must wait for returns.

Computing Profitability

If a value for each one of these factors is known or can be estimated for a young pine stand, then the amount and timing of each of the control costs and the amount of the control return can be estimated. These, in turn, can be used to determine the profitability of control as measured by a compound interest rate.

For example, a young pine stand subject to a medium weevil hazard, grown by a private owner who expects rising stumpage prices, under a management program that anticipates 200 twelve-inch d.b.h. crop-trees per acre at 60 years, is being considered for butt-log weevil control, with an estimated cost per treatment of $3 per acre. If the stand is growing on an average site, it will probably require about four treatments to protect the butt-log, the first one at about 6 years, followed by three more at 3-year intervals (table 7). The return for these expenditures will accrue when the stand is 60 years old and will amount to about $1.03 per crop-tree (table 5) or $206 per acre, which means about $10 to $12 per thousand board feet more than would have been received without control. Here is a compound interest formula that balances the series of costs with the return:

$$\$3\ (1.\ op)^{54}+\$3\ (1.\ op)^{51}+\$3\ (1.\ op)^{48}+\$3\ (1.\ op)^{45}=\$206$$

The unknown factor is p, the interest rate that just balances

costs and returns. In this case it is about 6.0 percent, and this is the rate of return that such a control investment would earn under the conditions assumed.

The Importance of Profit Factors

A rate of return like this one was determined for more than 1,500 control situations, each different from all the others with respect to one or more of the profit-determining factors. The rates of return for these many situations were then compared to see how important each of the factors was.

First, changes in the level of weevil hazard did not change the rate of return when other factors were held constant. The reason for this is that, as hazard increases, both control costs and control returns increase, and one almost exactly offsets the other. This means that although it may be very expensive to control weeviling under high-hazard conditions, control is just as good an investment as under less severe conditions because so much more is saved.

Second, control in the second log seemed just as profitable as control in the butt log, under similar conditions. It is true that less volume and quality are saved in the second log, and that control outlays are not too much different. But costs do not have to be carried forward so far to harvest, and this reduction in the waiting period makes second-log control equally as profitable as butt-log control.

Third, two of the remaining factors, crop-tree d.b.h. and number of crop trees per acre, can be replaced by a single factor, butt-log volume per acre at harvest, with little error.

Profit curves are presented in figure 14 for various price assumptions, rotation ages, and treatment costs, each curve showing the rate of return for various per-acre butt-log volumes at harvest. Rotation age and harvest volume are the most important profit determinants. Profit estimates are within 1 percent of computed value in most cases.

The individual manager, who may have the same price expectation, treatment cost, and planned rotation age for all his stands, will find that per-acre butt-log volume is his major determinant of profitability. Weevil control is most profitable in his well-stocked stands on good sites, least profitable on his poor sites in sparsely stocked stands. However, if he is contemplating a long rotation, there may be little difference in control profitability from one stand to the next—returns may be uniformly poor. Returns are much better when rotations are short simply because costs are not

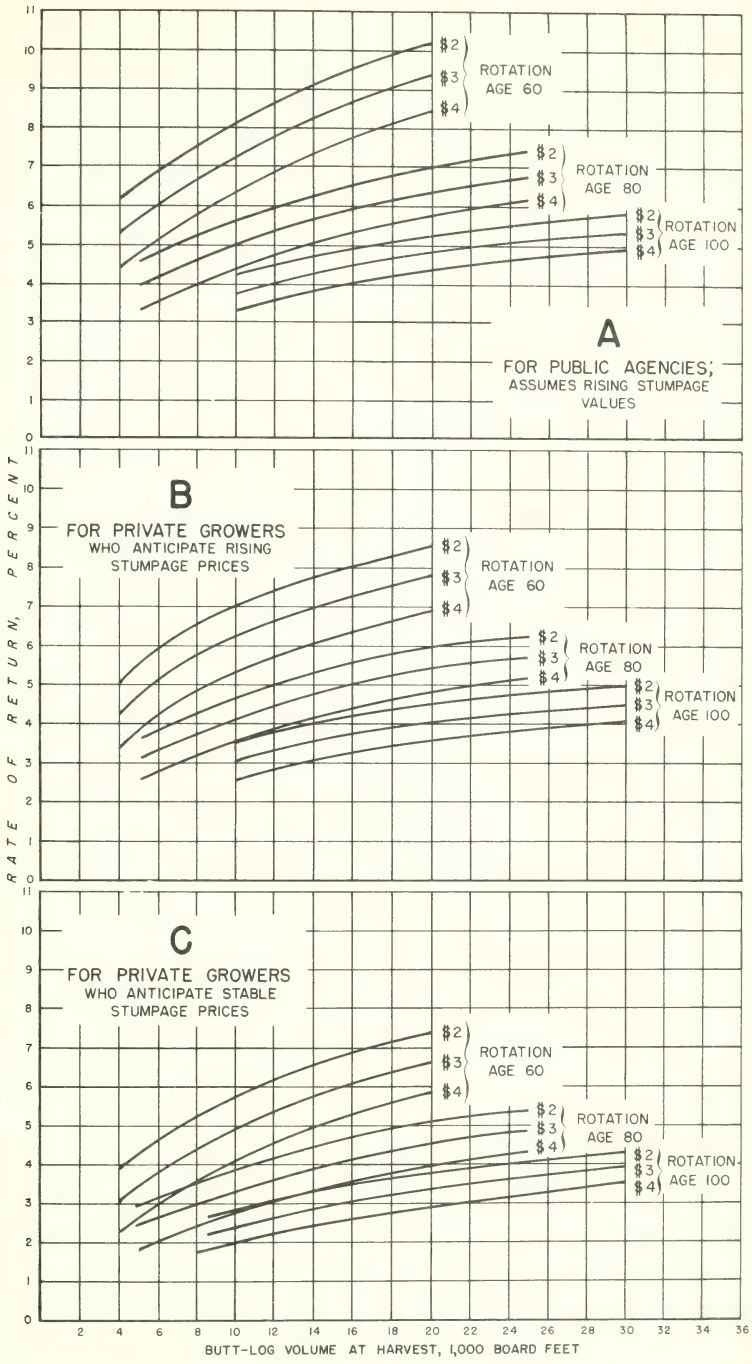


Figure 14.—Estimates of the profitability of weevil control.

Table 8.—Estimates of the rate of return from weevil control in well-stocked stands

Rotation age	Site Index[1]	Approximate butt-log volume per acre	Public agencies, Assuming rising stumpage prices and treatment cost per acre of—			Private growers					
						Assuming rising stumpage prices and treatment cost per acre of—			Assuming stable stumpage prices and treatment cost per acre of—		
			$2	$3	$4	$2	$3	$4	$2	$3	$4
Years	*Feet*	*Mbf.*	%	%	%	%	%	%	%	%	%
60	60-80	5	6.5	5.6	4.8	5.6	4.7	3.9	4.3	3.5	2.8
	90-100	10	8.1	7.2	6.3	7.0	6.2	5.4	5.8	5.0	4.2
80	40	5	4.5	3.9	3.3	3.7	3.1	2.6	3.1	2.5	1.9
	50	10	5.6	4.9	4.3	4.7	4.2	3.7	3.9	3.4	2.8
	60-70	15	6.3	5.7	5.1	5.5	4.9	4.3	4.6	4.0	3.5
	80-100	20	6.9	6.3	5.7	5.9	5.4	4.8	5.1	4.5	4.0
100	40	10	4.2	3.7	3.3	3.6	3.1	2.6	2.9	2.4	2.1
	50-60	15	4.7	4.3	3.9	4.1	3.7	3.2	3.4	3.0	2.6
	70-80	20	5.2	4.7	4.3	4.5	4.0	3.6	3.8	3.4	3.0
	90-100	25	5.5	5.1	4.6	4.8	4.3	3.9	4.1	3.7	3.3

[1] Use this column when there is no better basis for estimating butt-log volume at harvest. Well-stocked stands of the indicated site index and rotation age have the approximate butt-log volumes shown.

tied up so long at compound interest, and there is also likely to be a greater range in profitability, depending on site, stocking, and intermediate management when rotations are short.

Public pest-control program administrators may choose control sites from among many ownerships with differing rotation-age objectives. In addition to the site and stocking considerations that determine butt-log volumes at harvest, expected rotation age will greatly influence profits. Public weevil control might well concentrate on ownership classes where rotations are typically short. Here the government funds invested in control will generate returns in the shortest time and at the highest rates.

The data of figure 13 are summarized by table 8 in a form that may be somewhat easier to use. This table shows rates of return to control given rotation age, butt-log volume per acre at harvest, market outlook, and treatment cost per acre. An additional column for site index is given to show what site index must be for well-stocked stands to yield the indicated butt-log volumes at the indicated rotation age. Site index can be used instead of butt-log volume when there is no adequate basis for estimating volume. *Well-stocked* means that at least 75 percent of the stand area is occupied by pine trees spaced not further apart than 15 feet. Reduce butt-log volume one step for stands 50-to 75-percent stocked.

Ranking Control Opportunities

Estimates of profitability provide a criterion for ranking pine stands and so establishing control priorities. This can be done by:

- Listing all stands of young pine reproduction that are to be managed for pine sawlog production, with their acreages, from management records, maps, etc.
- Estimating butt-log volume per acre at harvest for each stand by projecting number of crop-trees per acre at harvest along with their average d.b.h.; or by using the site-index method.
- Determining the rate of return to control from table 8 for the market expectation, planned rotation age, treatment cost, and butt-log volume.
- Arranging stands in descending order of profitability.

A hypothetical array of eight stands, with the information called for above, is shown in table 9. This listing ranks stands in order of profitability as best this can be judged. Thus it establishes a priority of available control opportunities. The manager can choose any rate of return that seems appropriate as his minimum acceptable rate, and then needs to consider only those stands that

Table 9.—A hypothetical priority ranking of white-pine weevil control sites

Stand Designation	Size	Planned rotation age	Estimated crop-tree volume at harvest	Rate of return to control[1]
	Acres	*Years*	*M bd. ft.*	*Percent*
14C	20	60	16	7.2
8B	5	60	12	6.6
27B	63	60	10	6.2
12B	12	60	10	6.2
32	12	80	24	5.7
107	44	80	18	5.2
63A	130	100	30	4.5
42C	83	100	22	4.1

[1] Rates of return, assuming a treatment cost of $3 per acre and a rising stumpage price for a private grower, are taken from figure 18 rather than table 8.

promise an equal or greater return. The acceptable rate of return in table 9 is 5 percent; this is represented by a dashed line dividing the upper, acceptable stands from the lower, unacceptable ones. A ranking of this sort can help in deciding where to practice control by identifying the stands where control is likely to be sufficiently profitable.

SCHEDULING CONTROL

The Importance of Timing

After control sites have been selected, several questions involving the timing of control treatments remain to be decided. It is very important to initiate and repeat control treatments in individual stands at the proper time. Treatments ought to be neither too soon nor too late if control is to be maintained at least cost over a rotation.

Many stands of pine reproduction, both planted and natural, have a thousand trees or more per acre. In these stands weevil injury can proceed, perhaps for some time, and still leave an adequate number of uninjured pines from which to choose well-spaced crop trees. In sparsely-stocked stands, particularly where weevil hazard is high, very early treatment may be needed to preserve even a minimum number of uninjured straight pines. Similarly, there will be substantial differences from one stand to the next in the length of time before re-treatment is necessary, depending on weevil hazard conditions, stocking density, average tree height, crop tree objectives, and the treatment used.

A particular pattern of treatment has been assumed in computing the rates of return to anticipate for control under various circumstances. These patterns assume a particular stand age at first treatment and a particular treatment interval, for each hazard condition (table 7). In practice the actual schedule of treatments may be somewhat different from those assumed, and it should be varied from one stand to the next to take into account local differences in the rate of weevil population buildup, stand density, and other such factors. Each control site, because it is to some degree unique, must be examined periodically so that the next control treatment can be scheduled when it is needed.

There has been too little experience with control to determine the optimum pattern for timing of treatments. At what weevil population level should control be initiated and repeated to reduce weevil injury to an acceptable level with the least control expenditure? Is population level best measured by injury rate, or is there some better measure? These are several of the questions that arise in control scheduling; there are many others.

There may be several benefits to initiating control before the number of never-weeviled trees has declined to the target number. First, early treatment provides a margin of safety in the form of extra undamaged trees in case weevil injury is greater than anti-

cipated in later years, or in case subsequent treatments must be postponed for one reason or another. These additional trees may also mean that there will be a larger number of undamaged trees from which to choose crop trees, and so a better chance of including more of the faster growing trees in the final crop. Then too, early treatments probably have a better chance of being highly effective than when treatment is delayed until weevil population levels are high. These potential benefits of early treatment must be weighed against the possibility of added cost. Early treatment may be more costly either because it adds extra treatments, or because it increases the average length of time between treatment and harvest and so increases interest charges.

Forecasting the Decline in Never-Weeviled Trees

It is possible to predict, with a known degree of precision, the rate at which the number of never-weeviled trees in a young pine stand will decline without control, using the information presented earlier. First, there are definite relationships between the percent of trees in a young stand that have never been weeviled before current attack occurs (this percent can be estimated by examining the plantation) and both the current rate of attack and the percent of these new attacks that occur on trees never before weeviled (figs. 7 and 9).

These relationships are used to forecast the decline in the number of never-weeviled trees as follows. Suppose examination shows that 80 percent of the trees in a young plantation have never been weeviled. If the weevil hazard for this stand is about average for the Northeast, 12 percent of the trees will be weeviled in the next attack period (fig. 9); and 72 percent of these new attacks will be on trees never weeviled before (fig. 7). This means that the percent of trees never weeviled will decline by (.72 x .12) or about 8.6 percent, leaving 71.4 percent of the trees injury-free after the next attack period. The attack rate in the subsequent attack period, and the way in which these attacks will be distributed, can be calculated in the same way from the value 71.4 percent, and so on for additional periods.

In this example the average rate of decline in percent of never-weeviled trees was assumed. However, it is apparent that some plantations experience faster-than-average rates of decline and others slower rates. This has been taken into account in preparing table 10, wherein the percentage of the trees that will remain free of injury in 1, 2, 3, 4, and 5 years is predicted for average

conditions (part A) and for two other rates of decline: slower than average (part B), and faster than average (part C).

In part A of table 10 there is an equal probability of observed values being higher or lower than the table values. Parts B and C of table 10 are constructed so that there are 3 chances out of 4 of having at least the proportion of injury-free trees indicated. The table is based on information from pine plantations and some uniform natural stands from many areas in the Northeast. It is not known whether it applies to more heterogeneous natural stands.

Table 10 can be used to determine whether and when treatment will be necessary during the next 5 years to maintain a given number of trees per acre in a never-weeviled condition. First, it is necessary to decide how many injury-free trees per acre are to be maintained. More than the planned number of crop trees should be maintained because some never-weeviled pines will be too close together for all to be crop trees, and because more than 5 years may be required to produce the desired length of injury-free bole. If twice the number of pines needed for crop trees is maintained in a never-weeviled condition by the initial treatment, this will be enough to provide for some loss between subsequent treatments and still leave enough to provide well-spaced crop trees. At this point one must also decide how high to extend control—one log, two logs, or some intermediate height.

Next, examine the trees on the tentative control site to determine: (1) the current percent of trees that have never been weeviled, (2) the percent of trees that were never weeviled until the last attack period, (3) the stand's present average height, (4) the average number of pines per acre, and (5) the average rate of height growth. This can be done by examining and measuring the pines on small plots appropriately located throughout the control site. Suitable sampling procedures should be developed to fit individual circumstances. Use table 6 to estimate the number of years remaining during which protection must be maintained. Table 6 gives the number of years for one-and two-log protection depending on present average height of pines and the average rate of height growth.

The pines on the sample plots are to be recorded in three categories: pines that have never been weeviled, pines that were first weeviled during the last attack period, and pines that were weeviled before the last attack period. The first category will indicate the present proportion of never-weeviled pines. The second category, added to the first category, will indicate the propor-

Table 10.—Predictions of the decline in proportion of pine never weeviled if control is not begun

A: THE AVERAGE RATE OF DECLINE

Use this part of the table only to determine whether weevil hazard is higher or lower than average in the stand or plantation. Estimates of percent never weeviled in this part of the table are constructed so that there is an equal probability of observations being above or below the estimate.

Percentage of pine observed to have been never weeviled in the first year of record	Percentage of pine expected to be never weeviled under average conditions—				
	1 year later	2 years later	3 years later	4 years later	5 years later
100	99	98	96	93	89
99	98	96	93	89	83
98	96	93	90	84	78
97	95	91	87	81	73
96	93	89	84	77	69
95	92	87	81	74	66
94	90	85	79	71	62
93	89	84	77	68	60
92	88	82	74	66	57
91	86	80	72	64	55
90	85	78	70	62	53
89	84	77	69	60	51
88	82	75	67	58	49
87	81	74	65	56	48
86	80	72	63	54	46
85	78	71	62	53	45
84	77	69	60	51	43
83	76	68	59	50	42
82	75	66	57	49	41
81	74	65	56	48	40
80	72	64	55	46	39
79	71	63	54	45	38
78	70	61	52	44	37
77	69	60	51	43	36
76	68	59	50	42	35
75	67	58	49	41	34
74	66	57	48	40	33
73	64	56	47	39	33
72	63	54	46	38	32
71	62	53	45	38	31
70	61	52	44	37	31
69	60	51	43	36	30
68	59	50	42	35	29

CONTINUED

Table 10.—Continued

Percentage of pine observed to have been never weeviled in the first year of record	Percentage of pine expected to be never weeviled under average conditions—				
	1 year later	2 years later	3 years later	4 years later	5 years later
67	58	49	41	34	29
66	57	48	41	34	28
65	56	48	40	33	27
64	55	47	39	32	27
63	54	46	38	32	26
62	53	45	37	31	26
61	52	44	37	30	25
60	51	43	36	30	25
59	50	42	35	29	24
58	49	41	34	29	24
57	48	40	34	28	23
56	47	40	33	27	23
55	46	39	32	27	22
54	46	38	32	26	22
53	45	37	31	26	21
52	44	36	30	25	21
51	43	36	30	25	20
50	42	35	29	24	20
49	41	34	28	24	20
48	40	33	28	23	19
47	39	33	27	23	19
46	38	32	26	22	18
45	38	31	26	22	18
44	37	30	25	21	18
43	36	30	25	21	17
42	35	29	24	20	17
41	34	28	24	20	16
40	33	28	23	19	16
39	32	27	22	19	16
38	32	26	22	18	15
37	31	26	21	18	15
36	30	25	21	17	14
35	29	24	20	17	14
34	28	23	19	16	14
33	27	23	19	16	13
32	27	22	18	15	13
31	26	21	18	15	12
30	25	21	17	14	12
29	24	20	17	14	12
28	23	19	16	13	11

CONTINUED

Table 10.—Continued

Percentage of pine observed to have been never weeviled in the first year of record	Percentage of pine expected to be never weeviled under average conditions—				
	1 year later	2 years later	3 years later	4 years later	5 years later
27	22	19	16	13	11
26	22	18	15	13	11
25	21	17	14	12	10
24	20	17	14	12	10
23	19	16	13	11	9
22	18	15	13	11	9
21	17	15	12	10	9
20	17	14	12	10	8
19	16	13	11	9	8
18	15	13	11	9	7
17	14	12	10	8	7
16	13	11	9	8	7
15	13	11	9	7	6
14	12	10	8	7	6
13	11	9	8	7	6
12	10	8	7	6	5
11	9	8	7	6	5
10	8	7	6	5	4
9	8	6	5	5	4
8	7	6	5	4	3
7	6	5	4	4	3
6	5	4	4	3	3
5	4	4	3	3	2
4	3	3	2	2	2
3	3	2	2	2	1
2	2	1	1	1	1
1	1	1	1	1	0

CONTINUED

Table 10.—Continued

B: THE RATE OF DECLINE WHEN HAZARD IS LOWER THAN AVERAGE

Use this part of the table only after having determined that weevil hazard is lower than average, by comparing injury history with Part A of this table. Estimates in this part of the table are constructed so as to give 3 chances in 4 of having at least as many weevil-free trees as indicated.

Percentage of pine now never weeviled	Percentage of pine expected to be never-weeviled in—				
	1 year	2 years	3 years	4 years	5 years
100	99	99	98	97	95
99	98	97	95	93	89
98	96	94	92	88	84
97	95	92	89	85	79
96	93	90	86	81	75
95	92	88	83	78	72
94	90	86	81	75	68
93	89	85	79	72	66
92	88	83	76	70	63
91	86	81	74	68	61
90	85	79	72	66	59
89	84	78	71	64	57
88	82	76	69	62	55
87	81	75	67	60	54
86	80	73	65	58	52
85	78	72	64	57	51
84	77	70	62	55	49
83	76	69	61	54	48
82	75	67	59	53	47
81	74	66	58	52	46
80	72	65	57	50	45
79	71	64	56	49	44
78	70	62	54	48	43
77	69	61	53	47	42
76	68	60	52	46	41
75	67	59	51	45	40
74	66	58	50	44	39
73	64	57	49	43	39
72	63	55	48	42	38
71	62	54	47	42	37
70	61	53	46	41	37
69	60	52	45	40	36
68	59	51	44	39	35

CONTINUED

Table 10.—Continued

Percentage of pine now never weeviled	Percentage of pine expected to be never-weeviled in—				
	1 year	2 years	3 years	4 years	5 years
67	58	50	43	38	35
66	57	49	43	38	34
65	56	49	42	37	33
64	55	48	41	36	33
63	54	47	40	36	32
62	53	46	39	35	32
61	52	45	39	34	31
60	51	44	38	34	31
59	50	43	37	33	30
58	49	42	36	33	30
57	48	41	36	32	29
56	47	41	35	31	29
55	46	40	34	31	28
54	46	39	34	30	28
53	45	38	33	30	27
52	44	37	32	29	27
51	43	37	32	29	26
50	42	36	31	28	26
49	41	35	30	28	26
48	40	34	30	27	25
47	39	34	29	27	25
46	38	33	28	26	24
45	38	32	28	26	24
44	37	31	27	25	24
43	36	31	27	25	23
42	35	30	26	24	23
41	34	29	26	24	22
40	33	29	25	23	22
39	32	28	24	23	22
38	32	27	24	22	21
37	31	27	23	22	21
36	30	26	23	21	20
35	29	25	22	21	20
34	28	24	21	20	20
33	27	24	21	20	19
32	27	23	20	19	19
31	26	22	20	19	18
30	25	22	19	18	18
29	24	21	19	18	18
28	23	20	18	17	17
27	22	20	18	17	17

CONTINUED

Table 10.—Continued

Percentage of pine now never weeviled	Percentage of pine expected to be never-weeviled in—				
	1 year	2 years	3 years	4 years	5 years
26	22	19	17	17	17
25	21	18	16	16	16
24	20	18	16	16	16
23	19	17	15	15	15
22	18	16	15	15	15
21	17	16	14	14	15
20	17	15	14	14	14

C: THE RATE OF DECLINE WHEN HAZARD IS HIGHER THAN AVERAGE

Use this part of the table only after having determined that weevil hazard is higher than average, by comparing injury history with Part A of this table. The estimates in this part of the table are constructed so as to give 3 chances in 4 of having at least as many weevil-free trees as indicated.

Percentage of pine now never weeviled	Percentage of pine expected to be never-weeviled in—				
	1 year	2 years	3 years	4 years	5 years
100	91	80	76	61	49
99	90	78	73	57	43
98	88	75	70	52	38
97	87	73	67	49	33
96	85	71	64	45	29
95	84	69	61	42	26
94	82	67	59	39	22
93	81	66	57	36	20
92	80	64	54	34	17
91	78	62	52	32	15
90	77	60	50	30	13
89	76	59	49	28	11
88	74	57	47	26	9
87	73	56	45	24	8
86	72	54	43	22	6
85	70	53	42	21	5
84	69	51	40	19	3
83	68	50	39	18	2
82	67	48	37	17	1
81	66	47	36	16	0

CONTINUED

Table 10.—Continued

Percentage of pine now never weeviled	Percentage of pine expected to be never-weeviled in—				
	1 year	2 years	3 years	4 years	5 years
80	64	46	35	14	—
79	63	45	34	13	—
78	62	43	32	12	—
77	61	42	31	11	—
76	60	41	30	10	—
75	59	40	29	9	—
74	58	39	28	8	—
73	56	38	27	7	—
72	55	36	26	6	—
71	54	35	25	6	—
70	53	34	24	5	—
69	52	33	23	4	—
68	51	32	22	3	—
67	50	31	21	2	—
66	49	30	21	2	—
65	48	30	20	1	—
64	47	29	19	0	—
63	46	28	18	—	—
62	45	27	17	—	—
61	44	26	17	—	—
60	43	25	16	—	—
59	42	24	15	—	—
58	41	23	14	—	—
57	40	22	14	—	—
56	39	22	13	—	—
55	38	21	12	—	—
54	38	20	12	—	—
53	37	19	11	—	—
52	36	18	10	—	—
51	35	18	10	—	—
50	34	17	9	—	—
49	33	16	8	—	—
48	32	15	8	—	—
47	31	15	7	—	—
46	30	14	6	—	—
45	30	13	6	—	—
44	29	12	5	—	—
43	28	12	5	—	—
42	27	11	4	—	—
41	26	10	4	—	—

CONTINUED

Table 10.—Continued

Percentage of pine now never weeviled	Percentage of pine expected to be never-weeviled in—				
	1 year	2 years	3 years	4 years	5 years
40	25	10	3	—	—
39	24	9	2	—	—
38	24	8	2	—	—
37	23	8	1	—	—
36	22	7	1	—	—
35	21	6	0	—	—
34	20	5	—	—	—
33	19	5	—	—	—
32	19	4	—	—	—
31	18	3	—	—	—
30	17	3	—	—	—
29	16	2	—	—	—
28	15	1	—	—	—
27	14	1	—	—	—
26	14	0	—	—	—
25	13	—	—	—	—
24	12	—	—	—	—
23	11	—	—	—	—
22	10	—	—	—	—
21	9	—	—	—	—
20	9	—	—	—	—

tion of never-weeviled pines that existed before the last attack period. Use this latter proportion, the percent of trees unweeviled before the last attack period, to enter part A of table 10, and find the expected percent never weeviled now in the *1 year later* column.

For example, if 71 percent of the pines were unweeviled before the last attack period, part A of table 10 indicates that 62 percent should now be in the never-weeviled category. Compare this expected percent with the actual percent now never weeviled as observed on your sample plots. If your observed percent is higher than the expected percent, it means that weeviling has been less severe than average, and you should use part B of table 10 to project the future decline in percent never weeviled. If your observed percent is equal to or lower than the expected percent, then weeviling is proceeding faster than average and you should use part C of table 10.

Part A of table 10, then, is used only to determine whether the stand's weevil hazard is less than average or more than average. This determination is not very reliable when using estimates of percent of trees never weeviled for only 2 years. Better estimates are possible if data for additional past years are reconstructed or if estimates from the first examination of a stand are retained and compared with subsequent injury rates found upon later examination. It is possible that generalized hazard maps will be constructed as weeviling records are accumulated. It is clear from present data that there are geographic differences, but they cannot be delineated as yet.

Use the percent now never weeviled to enter the appropriate line of the table (parts B or C) to estimate future declines in the percent of pines never weeviled. In using the table, the predictions of the proportion of the stand that will remain injury-free are read for each year in the future (up to 5 years) on the row corresponding to the present proportion never weeviled.

Find out (1) whether the percent of never-weeviled trees will decline below the percent you want to maintain during the next 5 years, and if it will, (2) how many years from now this will occur. This will give a date by which you should plan to have completed the first control treatment. If this date is several years from now you will have an opportunity to examine the stand next year and refine your estimate of when initial control will be necessary.

Scheduling Initial Control

You can develop a schedule for initial control by conducting this examining and forecasting procedure for each chosen control site. Table 11 illustrates the result of an examination for the hypothetical control sites shown in table 9. Remember that six of the original eight control sites were tentatively chosen for treatment because these six all promised more than a 5-percent return. Two were discarded because control would probably not be profitable enough for this owner on those sites. The initial control schedule (table 11) reveals that one of the six selected stands will not need treatment before the first log is formed. This stand can be dropped from the control schedule. The remaining stands will require the initial treatment at various dates in the future: two this year, one next year, and two 5 years hence.

Table 11.—A hypothetical scheduling computation for butt-log control

Stand designation	Rate of return to control	Pine density, in trees per acre	Desired number of never-weeviled trees per acre	Target proportion of never-weeviled trees	Proportion never-weeviled before last attack period	Proportion now never-weeviled	Weevil hazard	Time to target proportion	Present stand height	Rate of height growth per year	Time until butt-log is formed	Control needed within—
	%	*No.*	*No.*	*%*	*%*	*%*	*Class*	*Years*	*Feet*	*Feet*	*Years*	*Years*
14C	7.2	1,000	300	30	100	97	Above aver.	5+	12	1.8	4	([2])
8B	6.6	800	400	50	96	95	Below aver.	5+	4	1.4	11	5
27B	6.2	1,000	400	40	63	50	Above aver.	1	4	1.4	11	1
12B	6.2	600	400	67	85	75	Above aver.	1	6	1.4	10	1
32	5.7	800	300	38	80	65	Above aver.	2	8	1.6	7	2
107	5.2	600	300	50	88	85	Below aver.	5	2	1.2	14	5
63A	4.5	([1])	—	—	—	—	—	—	—	—	—	—
42C	4.1	([1])	—	—	—	—	—	—	—	—	—	—

[1] Dropped because rate of return is less than the acceptable rate of 5 percent (see table 9).
[2] Dropped because the butt log will have formed before the proportion of never-weeviled pines declines below the target proportion.

Allocating Control Effort

Data from examinations of areas slated for control will enable you to tentatively schedule treatment for particular areas several years in advance. For large properties or public control programs, much more treatment work may be needed in some years than in others, because of unequal areas of pine in different age classes, and because of differences in the rate of injury buildup. In peak years a strain is placed on available funds, personnel, and equipment; in slack years other tasks must be found for these funds, men, and equipment. One way of avoiding these ups and downs is to do the same amount of treatment every year. This will mean treating some stands before they need it in slack years and delaying treatment in some stands when the control load is heavier than average. But a fixed amount of treatment each year does allow efficient employing, training, and equipping of control personnel.

There is a middle path, between doing the needed control each year regardless of how large or how small, and doing a fixed amount of treatment each year regardless of needs, that is better than either extreme. The main idea is to provide some flexibility in the amount of treatment done each year. Some flexibility is needed because treatment opportunities fluctuate, and also because the funds available for treatment may change from year to year. Complete flexibility, however, is wasteful because it is difficult and inefficient to change the level of treatment operations markedly and repeatedly.

On most properties weevil control is probably one more incidental management task to be handled among a host of others. In most years the amount of treatment needed will not exceed what can be accomplished by regular personnel in the normal course of management. In peak years a decision must be made whether to employ, equip, and supervise temporary personnel, to contract the overload, or to delay treatment in some stands.

SUMMARY-
A PLANNING GUIDE

This report has presented many different sorts of information about white pine and the white-pine weevil, and these data have been used to develop guides for evaluating and scheduling weevil control. This final section contains a weevil-control planning guide.

This planning guide outlines the questions to be answered and the data needed in setting up a control project or program. It is adaptable, with little modification, to both private and public ownerships and programs, since the planning sequence and data needs are the same regardless of whose program it is. The guide is also meant to serve as a summary of this report, to organize and put into perspective the various sorts of information and analyses presented.

Step 1:
Basic Considerations

Examine your young pine plantations and areas of natural reproduction for weevil injury. Figure 3 will help you to recognize terminal injury caused by the weevil, and to distinguish it from similar injuries caused by other agents. If weeviling is prevalent in some young stands, it may be profitable to do control work, and so planning may be needed. However, consider this opportunity in the light of available funds and other opportunities. Some owners and public agencies, even though they have a weevil problem do not have the time or funds to do control work, or can use available time and funds to better advantage in other ways.

Step 2:
Choose a Control Method

If you decide to go ahead, the next step is to gain some knowledge and experience of various control techniques. Some of the literature references given will introduce you to several different control methods that have been tested in the field. Next, try to talk with others in your area who have done weevil control, and watch actual operations in progress. Dealers are sometimes willing to demonstrate their spray equipment, or to lend it for a trial. In any case you will want to look over the various sorts of spray equipment available and determine their costs. Check on insecticide prices too. If you can borrow equipment, or if you

decide to go ahead and purchase it at this point, make some trial runs with it. This will give you a chance to estimate your per-acre treatment cost, and to try different insecticide formulations for their effectiveness.

Step 3:
Decide on Control Objectives

There are four factors that must be considered at this point in the planning process. They can all be adjusted later if it seems necessary. Together these four factors determine your control objectives.

- The desired or target number of never-weeviled trees per acre.
- The target height to which control will be carried.
- The minimum acceptable rate of return to control.
- The maximum amount of control work you will be able to do during the first year.

The number of trees to aim at protecting depends on the number of crop trees needed. Generally, 150 to 200 crop trees per acre are needed to fully utilize most sites. Plan to protect about twice this many young pines in order to have some leeway in selecting crop trees later. Target height may be limited by the treatment technique you have chosen. Plan to protect second logs as well as butt logs if your control method allows. Decide on the lowest rate of return that will satisfy you, and try to estimate the maximum amount of control you can do in the first year.

Step 4:
Survey Young Pine Stands

Now you are ready to examine each young stand in detail to estimate control return and determine if and when treatment will be needed. Examine young pine stands that will be managed for sawlogs and that have not yet reached target height. You will need at least these data for each stand examined:

- Stand designation or location.
- Acreage.
- Anticipated rotation age.
- Site index.
- Number of pines per acre.
- Present average height.
- Rate of height growth.

- Proportion of pines now never weeviled.
- Proportion of pines first weeviled during the last attack season.

Make these estimates by sampling small groups of pines throughout each stand. Tables 8 and 10 will give you a return rate estimate and an estimate of the number of years to first treatment for each stand examined.

Step 5: Ignore Stands Where Control is not Warranted

You can ignore the stands that have rates of return below your minimum. Also ignore any stands that will reach target height before they will require treatment. Follow the procedures like those given in tables 9 and 11 to do this in an orderly fashion.

Step 6: Schedule the First Year's Control

The only stands you must make a decision on immediately are those that require control now. Single these out from the others and list them in descending order according to rate of return. Estimate the total control cost for each by multiplying the acreage by your per-acre treatment cost estimate. Add a cumulative cost column to the listing as well. This will tell you how far down the list of stands you can go with available funds. These stands will constitute your control program for the first year. Each offers adequate returns, needs control now, and can be treated with available funds.

Step 7: Begin Now to Plan for Subsequent Years

Make similar listings for 1 or 2 years in advance, showing the stands not scheduled for the first year. Plan now to re-examine next year's batch to make a final decision on whether to include them or not. This pre-planning will also allow you to plan for a change in the amount of control for the next year if this seems desirable.

A Last Thought

This report is meant to be a summary of current knowledge on two aspects of white-pine weevil control. It does not represent the final word on these subjects. Research continues, and new

field experience is constantly being accumulated. These will lead to improved scheduling and evaluation guides as time goes on.

But it is important to begin now to take advantage of more weevil control opportunities. Effective control techniques are available, and current knowledge is sufficient to suggest a sound basis for control planning, to encourage more persons to examine their weevil-control opportunities, and to act on them.

■

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Disking to convert hardwood-loblolly pine stands to pine in eastern Maryland

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RALPH W. MARQUIS, DIRECTOR

Disking to convert hardwood-loblolly pine stands to pine in eastern Maryland

■

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The Need for Treatment

PINE stands, chiefly loblolly pine, form the most valuable forest crops on many sites of Maryland's Eastern Shore, but cultural treatments are required to establish and maintain them in already wooded areas. Pure pine stands have usually developed only on old-field sites. When the pines are harvested, relatively worthless hardwoods tend to take over these old-field sites. Since the hardwoods form the climax type, the natural trend is toward more hardwoods. Only cultural treatments that effectively favor the establishment and dominance of pine can check this trend.

Several cultural measures can be used to accomplish this objective, and since 1951 the Maryland Department of Forests and Parks and the Northeastern Forest Experiment Station have co-

operated in studies to develop and test various possible treatments. These include:

1. A late-summer fire, applicable in certain years in pine stands after a seed-tree cutting (*3*, *5*, *6*).
2. Light winter fires or other treatments to condition pine stands before cutting (*7*).
3. Poisoning individual hardwoods (*1*, *4*).
4. Applying herbicides to the undergrowth with back-pack or tractor-mounted mistblowers (*2*).
5. Mechanical reduction of the undergrowth with heavy machines.

Several machine treatments have been tried in Eastern Shore forests. A small bulldozer, pulling a stump or a Ranger Pal plow to prepare strips 6 to 10 feet apart before a seed-tree cutting, did not provide adequate control of understory trees and shrubs (*3*, *6*). On the other hand, bulldozing with a large tractor (D8 or comparable) has been effective in converting predominantly hardwood stands to pine.

But, because many Eastern Shore soils are poorly drained, the usual bulldozing practice of windrowing the uprooted hardwoods has created problems. In some areas the ridges and mounds of uprooted trees and attached soil have interfered with the surface drainage. And because the ground water level is so high, free water often has stood for extended periods in the cleared patches where the soil surface had been lowered.

Disking is another possible mechanical treatment, and it has the merit of not disturbing the natural drainage. However, up to the middle 1950's, disking had not been tried on the Eastern Shore.

Since disking seemed to offer advantages over bulldozing, a study was started in 1956 to determine its effectiveness. Some of the questions we hoped to answer were:

- How intensively should an area be treated?
- What species and stem sizes of hardwood trees and shrubs are eliminated?
- Which ones are only set back and soon recover?

- How fast do these recover? (i.e., how long after treatment can pine seedlings start and still become dominant?)

This report describes what we learned about these questions and about the role of disking in Eastern Shore timber management.

Study Methods

TREATMENTS

Three treatments were tried, each in two 1.2-acre plots (6 chains by 2 chains) in August 1956. These were:

1. Blading. — A D4 bulldozer was used alone, with the bottom of the blade set 1 to 2 feet above the ground. Only trees that could be uprooted easily, usually on the first attempt, were pushed over. Trees and shrubs that were broken off or uprooted were not windrowed.

2. Single disking. — In this treatment an Athens disk[1] was pulled behind the bulldozer, with the blade set in the same

[1]All of the later disking in eastern Maryland has been done with Rome disks, and private contractors generally use D6 bulldozers.

Figure 1.—Disking in an Eastern Shore stand similar to the study plots. Note the dense growth of small hardwoods and shrubs in the background, and the absence of any mineral soil showing in the foreground. Note also the absence of upturned root systems of shrubs and small hardwoods; they have been bent down or broken off, not uprooted.

position as in treatment 1; so the single disking actually was a once-over combination of blading and disking (fig. 1).

3. Double disking. — The third treatment differed from the second only in intensity: the area was disked twice, the second passes crossways to the first.

In all plots the operator treated as much of the area as the machine could easily reach. A few spots near large trees were not treated, but about 90 percent of each plot was disturbed to varying degrees.

Hardwoods 4 inches d.b.h. and larger were not usually pushed over. These were treated with 2,4,5-T in ax frills (8 pounds acid equivalent per 100 gallons of No. 2 fuel oil) in late August after the tractor treatments had been completed.

MEASUREMENTS

To provide data on stand composition before treatment, trees larger than 3.5 inches d.b.h. were tallied by species and 1-inch diameter classes on the inner 0.5 acre of each plot.

Within each 0.5-acre plot five 1-chain strips were randomly selected and referenced to large trees before the tractor treatments were made. These strips provided 50 permanently marked milacre-quadrats in each plot.

Data collected on each quadrat before treatment and 1, 3, and 5 years after treatment included:

- A tally of all trees less than 3.6 inches d.b.h., by species and size classes (0.0-0.5 foot tall, 0.6-1.5 feet, 1.6-3.5 feet, 3.6 feet tall-0.5 inch d.b.h., 0.6-1.5 inches d.b.h., and 1.6-3.5 inches d.b.h.). In sprout clumps, only the tallest member was included. In the 1957 tally, the apparent fate was noted for all stems in the original tally.
- A list of shrub species present, an estimate of the shrub cover to the nearest 5 percent, and the height of the tallest shrub.
- Cover and depth of forest floor. Cover was estimated to the nearest 5 percent, and depth was estimated, on the basis of at least 2 measurements, to the nearest ½-inch.

Character of the Stand

The study was located in a hardwood-pine stand in the Pocomoke State Forest, Worcester County, Maryland. Before treatment the stand contained more than 6,000 trees per acre, most of which were small (fig. 1). Only 96 stems per acre were 8 inches or larger in diameter, and only 121 per acre were between 4 and 7 inches. Hardwoods predominated. Holly and red oaks (chiefly water oak and southern red oak) were the most common species, followed by sweetbay, loblolly pine, red maple, white and post oaks, blackgum, and sweetgum (table 1).

Although loblolly pine made up only 8 percent of the stems of all sizes, the 23 pines per acre that were 8 inches or larger in diameter did provide a good seed source. Most of the tallied pines—88 percent—were less than 3.5 feet tall. These seedlings under 3.5 feet tall and the occasional taller pine seedlings and saplings were usually overtopped and deformed by competing vegetation. The amount of pine reproduction, 435 seedlings per acre, was far from sufficient to form a well-stocked stand, even if it could have been easily released.

Although some shrubs in all plots reached heights of 13 to 15 feet, the average heights of the tallest shrubs on the measured quadrats were 6 to 9 feet. Except under hollies, the shrub layers tended to be dense (fig. 1), shading 65 to 85 percent of the forest floor.

Common members of the shrubby understory were sweet pepperbush (*Clethra alnifolia*), fetter-bush (*Leucothoe racemosa*), and catbrier (*Smilax rotundifolia*). Somewhat less common were high-bush blueberry (chiefly *Vaccinium corymbosum*), azalea (*Rhododendron* sp.), winterberry (*Ilex* sp.), teaberry (*Gaultheria procumbens*), chokeberry (*Pyrus* sp.), shadbush (*Amelanchier* sp.), huckleberries (*Gaylussacia frondosa, G. baccata*), inkberry (*Ilex glabra*), maleberry (*Lyonia ligustrina*), bayberry (*Myrica pensylvanica*), and low-bush blueberry (*Vaccinium vacillans*).

As the composition of the shrub growth indicates, the site was poorly drained. Wherever a tree had been windthrown, the

Table 1.—*Stand composition before treatment, by species and size class*

(In number of stems per acre)[1]

Size class	Pine	Red oaks[2]	White oaks[2]	Sweet-gum	Black-gum	Red maple	Holly	Sweet-bay	All species
0.0-0.5 feet tall	274	1,467	50	—	3	13	820	400	3,027
0.6-3.5 feet tall	163	350	47	10	37	53	943	100	1,703
3.6 feet tall to 1.5 inches d.b.h.	30	130	23	57	140	100	437	57	974
1.6-3.5 inches d.b.h.	3	3	13	13	10	27	100	13	182
3.6-5.5 inches d.b.h.	4	13	14	1	6	15	20	5	78
5.6-7.5 inches d.b.h.	1	8	13	2	4	11	4	—	43
7.6-9.5 inches d.b.h.	5	6	10	1	1	11	5	—	39
9.6-13.5 inches d.b.h.	6	5	10	—	2	9	3	—	35
13.6-23.5 inches d.b.h.	12	1	5	—	1	3	—	—	22
Subtotals:									
Less than 4 inches d.b.h.	470	1,950	133	80	190	193	2,300	570	5,886
4-7 inches d.b.h.	5	21	27	3	10	26	24	5	121
8 inches d.b.h. and larger	23	12	25	1	4	23	8	—	96
Total, all sizes	498	1,983	185	84	204	242	2,332	575	6,103

[1]Includes all seedlings and the largest member of each sprout clump in the size classes below 3.6 inches d.b.h. All multiple stems more than 3.5 inches d.b.h. are included in this table.

[2]Chiefly water and southern red oaks in the red oak group; white and post oaks in the white oak group.

resulting hollow in the soil surface held standing water except in extended dry periods. The forest floor was relatively deep—slightly more than 4 inches on the average.

Results

EFFECT ON HARDWOOD TREE SPECIES

Advance Reproduction

The three treatments differed surprisingly little in their effect on advance hardwood tree reproduction. The blade treatment eliminated 37 percent of the stems 1.6 feet tall to 3.5 inches d.b.h., single disking eliminated 44 percent, and double disking 50 percent. Or if reduction of stems of this same original size class to heights of less than 1.6 feet in the first year is used as the criterion, the difference among treatments was still slight: in the blade treatment 60 percent of the stems were either eliminated or had sprouts less than 1.6 feet tall in 1957; in the single disking, 65 percent; in the double disking, 75 percent.

The treatments affected all species similarly, except sweetbay: 11 to 24 percent more stems of this species than of the other hardwoods were eliminated.

Size of the advance hardwood reproduction had no appreciable effect on the proportion of stems eliminated by a treatment.

Size class and treatment did affect the proportion of stems that survived without any appreciable loss in height. As table 2

Table 2.—*Proportion of advance hardwood reproduction that survived without dropping in height class*

Treatment	Hardwoods 0.6 to 3.5 feet tall	Hardwoods 3.6 feet tall to 3.5 inches d.b.h.
	Percent	*Percent*
Blade	58	20
Single disking	42	18
Double disking	34	14

Table 3.—*Effect of treatments on number of pines and hardwoods less than 3.6 inches in diameter (b.h.)*

Number of seedlings and sprout clumps per acre

Treatment	Time	Pine	Oaks	Black-gum	Sweet-gum	Red maple	Holly	Sweet-bay	All hardwoods
Blade	Before treatment	230	1,530	270	120	170	1,140	430	3,660
	After treatment[1]	6,820	1,480	710	290	6,820	1,100	220	10,620
	Change	+6,590	−50	+440	+170	+6,650	−40	−210	+6,960
Single disking	Before treatment	600	2,980	190	60	220	3,060	580	7,090
	After treatment	19,810	2,440	320	200	12,220	2,830	290	18,300
	Change	+19,210	−540	+130	+140	+12,000	−230	−290	+11,210
Double disking	Before treatment	580	1,740	110	60	190	2,700	700	5,500
	After treatment	21,850	1,560	300	210	22,660	3,380	300	28,410
	Change	+21,270	−180	+190	+150	+22,470	+680	−400	+22,910

[1]In August, about 1 year after treatment.

shows, drops in height class were 20 to 38 percentage points less among hardwoods under 3.5 feet tall than among taller ones up to 3.5 inches d.b.h. Furthermore, differences among treatments were considerably more for the smaller than for the larger hardwoods, as demonstrated by the 24-point spread in column 1 of the table versus the 6-point spread in column 2.

The results indicate that the blade and track action of the bulldozer itself accounted for most of the elimination of advance hardwood reproduction, and for much of the reduction in height of surviving stems. Disking increased the numbers eliminated, but had its most marked effect in reducing the height of the small hardwoods (less than 3.5 feet tall), most of which were not broken by the blade.

Subsequent Hardwood Reproduction

The treatments greatly encouraged the establishment of new hardwood tree reproduction, especially of certain species. Red maple was by far the most prolific (table 3), and the amount of new reproduction increased with intensity of treatment. Probably because of a poor seed source, sweetgum establishment was not markedly favored. However, it responded more than oaks or sweetbay.

Regrowth

Recovery of the hardwood understory has been rapid. After 3 years the intensity of treatment still was reflected in the average height of the tallest hardwoods on the study quadrats: 4.0 feet after only blade treatment, 3.6 feet after single disking, 2.9 feet after double disking.

But in 2 more years these stems had reached 5 to 7 feet in all plots, and the effect of treatment intensity was largely obscured. Then the only noticeable differences among treatments in the amount and size of hardwood growth were those associated with differences in the frequency of spots so severely disturbed that little advance hardwood reproduction had survived. Frequency of these spots of course increased with intensity of treatment.

EFFECT ON SHRUBS

Although none of the treatments eliminated any shrub species, all treatments greatly reduced shrub cover and height. After 1 year the cover was 65 percent of the initial amount in the blade treatment, 54 percent in the single-disking treatment, and 43 percent in the double disking. By then, all treatments had reduced the average height of the tallest shrubs by 4 to 5 feet.

On most of the area, shrubs regained their original density within 3 years after treatment. After 5 years, the tallest shrubs on the quadrats were still somewhat under their original height, but the average level of shrubs was as high as before treatment. Though the recovery of shrubs was slower after disking than after the blade treatment, the only noticeable difference after 5 years was in the severely disturbed spots. Shrub recovery there was still slow, and since the area in these spots varied with intensity of treatment, so did the reduction of shrub competition.

EFFECT ON FOREST FLOOR

The three treatments had little effect on the cover and depth of the forest floor, even though at the time of treatment some modification apparently occurred. Intensity of treatment seemed initially to affect the amount of mineral soil showing, but after 1 year no difference was discernible. The quadrat data indicated a reduction, after 1 year, of only 2 to 4 percent in area covered by forest floor, and a reduction of only 0.4 to 0.8 inch in depth.

Of course, on drier sites with thinner floor, or in more open stands (where there were fewer stems for the disk to ride on), disking has turned under a much higher proportion of the organic mat.

EFFECT ON PINE REPRODUCTION

All treatments eliminated most of the advance pine reproduction. No pines in the 3.6-feet-tall to 3.5-inch-d.b.h. size range survived on the quadrats. Pines shorter than 3.6 feet were less susceptible: 12 to 20 percent of these were living in 1957.

All treatments greatly increased the amount of new pine reproduction. Even the blade treatment resulted in 6,590 more pine seedlings per acre at the end of the first growing season, and adding a disking treatment nearly tripled the increase. Doubling the amount of disking did not favor additional pine reproduction so much as it did additional hardwood reproduction (table 3).

Though new pine reproduction stocked 93 to 99 percent of the quadrats in all treatments during the first year, seedlings were both more numerous and taller in the disked areas. Seedlings taller than 0.5 foot in their first growing season were found on 19 percent of the quadrats after the blade treatment, on 52 percent after single disking, and on 57 percent after double disking.

In the following 4 years the amount of pine reproduction dropped markedly, but all treatments still had more than 3,000 seedlings per acre (table 4). However, only in the disked plots were nearly all quadrats still stocked with pine seedlings. Much of the surviving pine reproduction was overtopped by hardwoods and shrubs, especially in the blade treatment. Pines free to grow were about twice as common in the disked plots as in the blade treatment (figs. 2 and 3), and slightly more common in the double-disking treatment than in the single-disking one (table 4). But even in the disked plots some release of pine reproduction will be needed if it is to form a relatively pure stand.

Table 4.—*Amount of pine reproduction, milacre quadrats stocked with pine seedlings, and quadrats with pine free to grow 5 years after treatment*

Treatment	Pine seedlings per acre	Quadrats stocked by pine	Quadrats with pine free to grow[1]
	Number	*Percent*	*Percent*
Blade	3,190	63	20
Single disking	7,250	94	36
Double disking	6,170	91	47

[1]When questionable quadrats are included, the values become respectively: 28, 53, and 62.

Figure 2.—Typical view after 6 years, in area treated by blading. In spots, as in the center, pines are becoming dominant. Elsewhere regrowth of shrubs and hardwood sprouts has captured the site.

Discussion of Results

Though the treatments created conditions that were very favorable for the establishment of pine reproduction, the favorable conditions did not last long. Seedbed conditions, although modified only slightly and temporarily, were good enough to enable an abundance of seedlings to start. But regrowth of hardwood trees and shrubs was so rapid that usually only the pine seedlings starting in the first spring after treatment had a chance of becoming dominant.

This chance increased with intensity of treatment. Single disking, as compared to the blade treatment after 5 years, almost

doubled the amount and the dominance of pine reproduction (table 4). Double disking resulted in still more dominant pine reproduction. However, the increase from double disking was comparatively small — not enough to warrant the extra expense.

Thus, even though much of the initial disturbance was created by the tractor blade and tracks, the addition of the disk was highly worthwhile. The blade and tracks of the tractor were responsible for most of the uprooting or breakage of hardwood trees and shrubs taller than 3.5 feet, and also for some of the disturbance to the smaller growth and to the forest floor. Much of the disk's effect was in reducing the height and cover of shrubs and trees that were less than 3.6 feet tall. This effect, plus some slight influence of the disk on taller plants and on

Figure 3.—Small pines dominate the new stand in portions of the disked plots, especially where disturbances were relatively severe. This shows a double-disked area 6 years after treatment.

the forest floor, greatly favored the establishment, rapid growth, and eventual dominance of pine reproduction.

Even so, release of the pines is needed on our plots, as is true of many areas that have been disked on the Eastern Shore. Without release, only partial restocking to pine usually is obtained, especially on wet, poorly drained sites like our study area. On drier sites hardwood tree and shrub competition is less aggressive, and disking alone is frequently proving adequate.

Our results differ somewhat from those described by Trousdell and Wenger (*8*) for North Carolina. They found that initial stocking was a good criterion of third-year stocking of free-to-grow seedlings. Although stocking levels varied with differences in soil texture and in basal area of residual hardwoods larger than 4.5 inches d.b.h., this relationship generally held: that high initial stocking portended high third-year stocking and vice versa. In our study, high initial stocking (93 to 99 percent) did not assure good stocking of free-to-grow seedlings 3 years later.

The soil relationships reported by Trousdell and Wenger also are different than in our region. They found that hardwoods are slower growing and form less competition on heavy-textured soils than on light-textured soils. The reverse is true on the Eastern Shore.

Since our disking study was established in 1956, important developments have occurred in the use of chemical herbicides in silviculture. Mistblower treatments with 2,4,5-T are proving to be particularly effective and practical for the selective release of pines from shrubs and small hardwood trees (*2*). Larger trees require poisoning by frill or injector treatment. The pines on our disked plots undoubtedly could be released sufficiently by mistblower treatment to assure a predominantly pine stand.

However, the combination of disking and chemical treatments is not cheap; it is fully as expensive, or more so, than bulldozing (which costs about $35 an acre). Disking costs from $15 an acre (on large tracts) to $26 an acre (on small tracts); poisoning the larger hardwoods left after disking runs about $10 an acre; and the later mistblowing about $12 an acre — for total costs of $37 to $48 an acre where all three measures are needed.

One alternative in converting hardwood-pine stands may prove to be somewhat less expensive; namely, a combination of mistblowing and subsequent injector treatment of surviving hardwoods, without disking. However, chemical treatments cost more where understories have not been reduced by disking. With no prior understory reduction, mistblowing costs may be about $15 an acre and injector treatment costs about $18, adding up to total costs in the range of $30 to $35 an acre.

Another use of disking, besides its use in converting hardwood-pine stands, could be in conditioning essentially pure pine stands for regeneration. Here the treatment would be applied in thinned or shelterwood-cut stands before a seed-tree cutting. However, unless the hardwood understory were naturally rather sparse or had previously been reduced by fire, disking probably would be followed by so much regrowth that later release of the young pines would be required. Mistblowing, therefore, might better be used in the first place. In most situations on the Eastern Shore, it would be a more effective conditioning treatment than disking.

Summary

In August 1956, three treatments for converting mixed stands to pine were tried in a hardwood-pine stand on Maryland's Eastern Shore: (1) blading with a D4 bulldozer, with the blade carried 1 to 2 feet above ground, which broke off or uprooted the smaller trees and larger shrubs; (2) single disking with an Athens disk drawn by the same bulldozer with blade as in treatment 1; and (3) double disking, done as in treatment 2 but twice over, with the second passes made crossways to the first ones. Each treatment was applied on two 1.2-acre plots. After these mechanical treatments, residual hardwoods larger than 3 inches d.b.h. were frill-poisoned on all plots.

Much of the effect in all treatments was from the action of the blade and tracks of the bulldozer. The bulldozer was responsible for most of the uprooting and breakage of hardwood trees and shrubs taller than 3.5 feet, and it also had some effect

on smaller vegetation and the forest floor. The disking eliminated some more of the hardwoods, but its main effects on the understory were to reduce the density and height of stems in the 3.5-foot and shorter height classes. Disking also greatly increased establishment of pine seedlings. Double disking had still more effect, but not enough to warrant the additional expense.

So many hardwood trees and shrubs survived, and their regrowth was so rapid, that treatment effects in reducing competition to small pines were very temporary. Pine seedlings have to be promptly established, either naturally or by planting, if they are to have a chance of becoming dominant after such treatments. Except on some of the drier sites, disking alone is inadequate preparation for establishment of nearly pure pine stands; it has to be supplemented by later selective release, such as can be done by application of an herbicide with a mistblower.

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